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Application of Sludges and Wastewaters on Agricultural Land: A Planning and Educational Guide

Edited by

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Section 1

INTRODUCTION
for Application of Sludges and Wastewaters on Agricultural Land (A Planning and Educational Guide)

Bernard D. Knezek and Robert H. Miller

Under the Federal Water Pollution Control Amendments of 1972, land application is recognized as an alternative method for effecting stages of wastewater treatment and for ultimate disposal of solid wastes. For certification and shared-cost funding under this legislation, a waste treatment proposal must include evidence that the plan is based on "the best practicable technology" and "the most cost effective method(s) over the life of the works." Requirements for compliance are phased over periods of years and advance by stages toward the goal of "eliminating discharge of all pollutants into navigable surface waters by 1985."

The idealized goal of "zero discharge" is neither practical nor wholly desirable. Nevertheless, it is to be expected that the quality and permissible uses of waters originating in waste treatment operations will come under increasing regulation at all levels of government. Discharge standards ultimately adopted will vary with background levels in natural waters from one locality or region to another and will be subject to periodic revision as new technologies evolve for assessing environmental impact and for effecting rational control.

The capacity of soils to receive wastewater and sludges and to inactivate contaminants varies greatly, depending upon a variety of soil, plant, and climatic factors. Generally, most well-aerated soils are quite efficient in organic matter conversion so that BOD loading is not a direct problem. Certain nutrients (such as nitrate) which are produced by organic breakdown may become a problem at high loading rates. Soils with high water infiltration capacity, which would allow large water loading rates, may be ineffective in trapping nutrients even though BOD elimination is rapid. Therefore, the soil selected for waste application on land must be chosen on the basis of waste characteristics, operation and management aspects, cropping systems, and other factors which make each decision an individual undertaking. Usually, the best soil for waste application is dictated by a necessary balance between potential soil loading rates and potential environmental contamination.

Emphasis in this document is directed toward utilization of agricultural processing, industrial, and municipal wastes through application on agricultural land. Animal wastes are covered in a separate document. (21)

Several basic points need to be clarified to establish the context within which all of the contributions of this document have been developed.

1. Land is a valuable natural resource and the viability and productivity must not be endangered during application of wastes.

2. The system must be managed so that normal agricultural production can be maintained without sacrificing crop quality or yield.

3. A balanced system must be established so that the finite limits of the regeneration processes of the soil are not exceeded.

4. Primary emphasis is upon utilization of the usable resources in the waste constituents rather than providing a disposal site.

Who will be the primary users of the information provided by the numerous professionals who have contributed to this document? Throughout its compilation, the editors have considered a broad potential audience. Personal experiences of both have shown that a broad spectrum of individuals and professions naturally become involved when a municipality makes a decision to consider land application of wastewaters and/or sludges; *e.g.*, municipal officials, other community leaders, health officials, sanitary engineers, consulting engineers, farmers, extension agents, soil conservation personnel, mass media representatives, teachers, and local citizens with a desire to be better informed.

This document is not intended to provide final design criteria and information which could be used to totally design and manage a land application system. Rather, it is to be used as a planning tool by people who must plan, as an educational tool for those who must educate, and as an information vehicle for those who desire information. For this reason, the individual contributions have been organized in a manner which it is hoped will lead interested people logically through the decision-making or educational processes. A loose-leaf format was selected to allow for updating of various sections as more information becomes available without the need to reprint the entire document. This will undoubtedly happen frequently in the next 5 years in the area of heavy metals and nitrogen reactions, where considerable research is rapidly reaching fruition.

Application of these same wastes to forested land, greenbelts, parks, golf courses, or land reclamation areas is not considered specifically. Yet, the principles involved and discussed can often be applied to these locations as well.

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Section 2

SITE SELECTION CONSIDERATIONS for Sludge and Wastewater Application on Agricultural Land

George F. Hall, Larry P. Wilding, and A. Earl Erickson

Site selection criteria consider those characteristics of the soil and landscape which will lead to the renovation of sludge and wastewater solids without creating environmental problems outside the site perimeter. The basic objective is to apply sludge and/or wastewater to the soil in such a manner that the soil can assimilate the wastes and prevent the wastes and harmful by-products from moving onto adjacent land, into flowing water, or into the groundwater beneath the land.

The site selection criteria for wastewater renovation are in many ways very similar to those for sludges. There are, however, some very important differences. Three basic interrelated parameters will be discussed relative to the best possible site selection. These parameters include landscape features, soil parent material including geologic characteristics, and properties of the soil. It must be emphasized that soils and landscapes are very complex and the principles given here are only guidelines for the selection of a sludge and/or wastewater application site. On-site evaluation of soil and landscape conditions is essential prior to final site selection. These on-site investigations should be made by qualified soil scientists and supplemented in some cases by specialists such as geologists, hydrologists, engineers, etc. Assistance can be obtained from a number of organizations in each state, including:

- U.S. Department of Agriculture, Soil Conservation Service
- State Departments of Natural Resources or comparable agencies
- State Agricultural Experiment Stations, or Colleges and Universities with Departments of Agronomy or Soil Science
- Cooperative Extension Service
- Professional consultants with training and experience in the field of agronomic soil science
- U. S. Geological Survey.

Site Selection

An ideal site for sludge and wastewater utilization would have the following landscape, parent material, and soil characteristics. Keep in mind, however, that less than ideal sites may sometime be usable with proper design and management.

Landscape

- A closed or modified closed drainage system (Fig. 2.1)
- Slopes less than 4%; steeper gradients may be acceptable on coarse-textured soils or where management practices (see Sections 4 and 7) or application methods (see Sections 5 and 8) reduce erosion hazards.

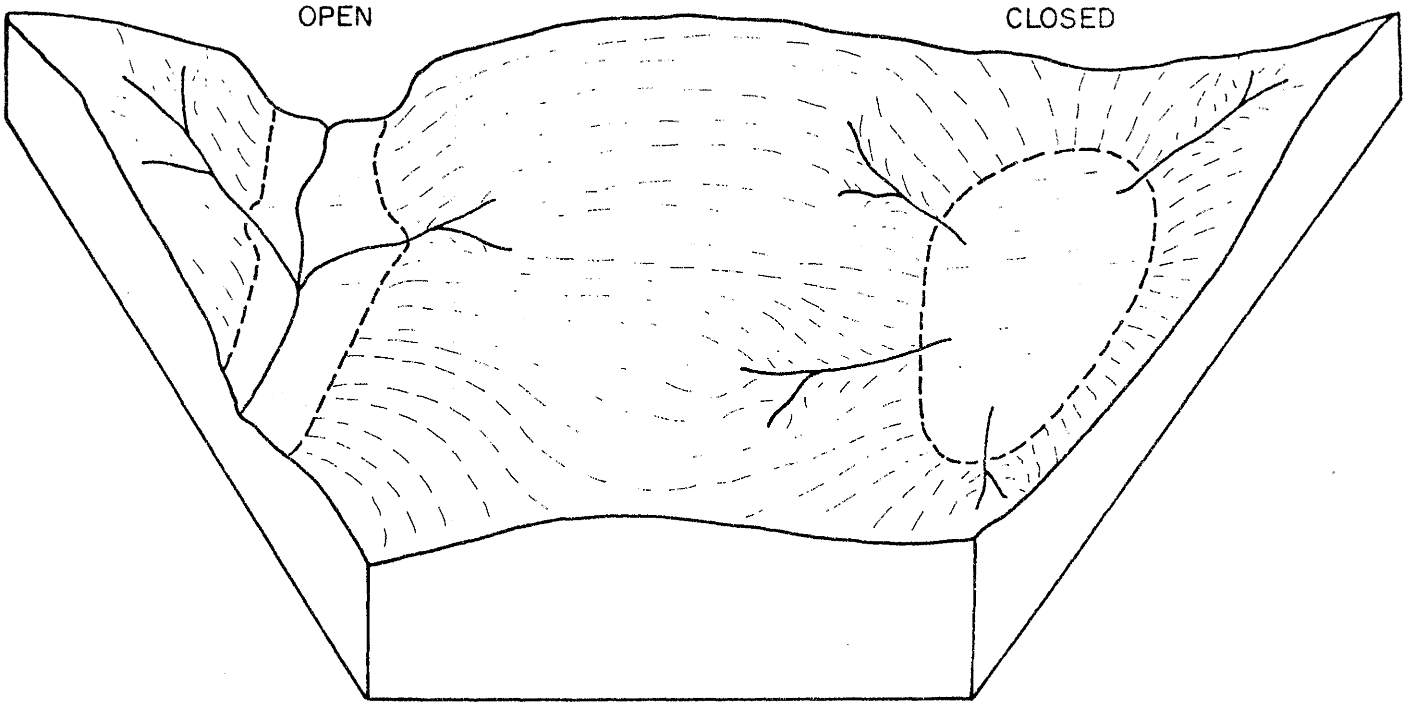

FIG. 2.1.--Diagrammatic representation of open and closed drainage systems.

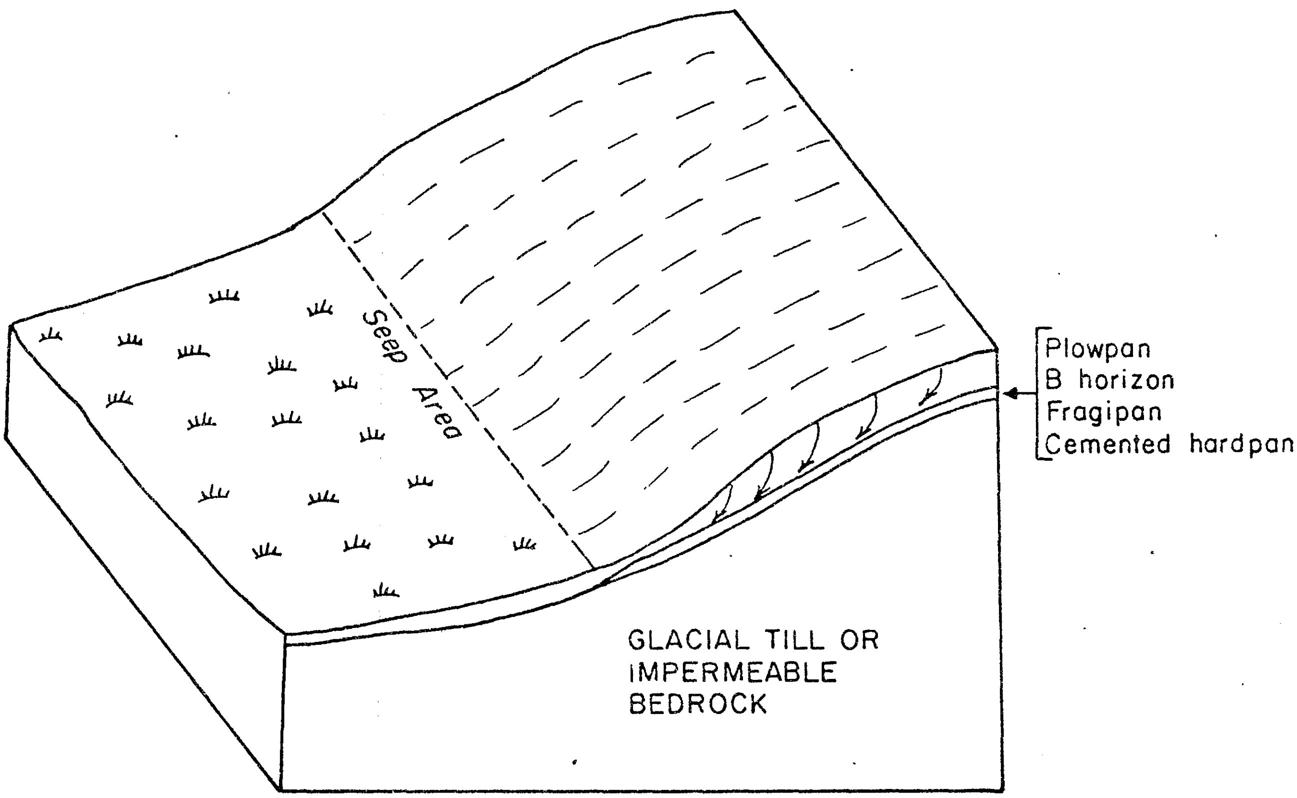

FIG. 2.2.--Diagrammatic cross-section of a sloping landscape showing the position of various restrictive layers.

Parent Material

- Medium-textured materials; finer-textured or high bulk density materials are suitable for sludges if managed properly and may be suitable for wastewaters if overland flow is used.

- High pH's and/or free carbonates (lime).

- Bedrock and unconsolidated substrata, when present, should be free of coarse conducting layers or conduits, and should always be at least 3 or 4 feet below the soil surface.

Soils

- High surface infiltration capacity and moderate subsoil permeability. (See Appendix A for methodology.)

- A soil thickness of at least 3 feet without restrictive layers.

- Well or moderately well-drained soil conditions to provide oxidizing conditions throughout most of the year; less well-drained soils if adequately tiled.

- Moderate to high moisture supplying capacity (15 to 20 percent by volume).

- Soil pH values ranging from 6.5 to 8.2.

- Medium and high levels of organic matter in the surface horizon.

A more detailed discussion of these site selection criteria is contained in the following paragraphs.

Landscape Position

Position on the landscape is of major importance because it asserts a major influence on surface and subsurface water movement (hydrology of area); it influences the amount of soil erosion and therefore the amount of sludge, wastewater, and by-products which may move off the site; and it asserts a secondary influence through its control on the kinds of soils found in the watershed.

Two general landscape drainage systems exist; the open and the closed system (Fig. 2.1). The open drainage system of most humid and subhumid areas permits the movement of sediment and soluble material from a given site to the watercourse and then to the major sediment loads in streams and rivers.

In contrast, the closed drainage system of some arid and semiarid areas is a landscape where essentially all products derived within the perimeter are trapped within the system and are not transmitted to major streams or underground water supplies. Excess water is ponded and evaporates or filters for short distances through the soils in these areas. These systems contribute little to the pollution of the environments outside their perimeter.

In the selection of a site for sludge utilization, a landscape consisting of or approaching a closed drainage system is most desirable. Containment of the sludge and its by-products is necessary until the risk from potential environmental contaminants has been removed by physical, chemical, or biological reactions of the soil.

A modified closed system can easily be developed on a nearly level landscape by the erection of small ridges across the outlet of the drainage basin.

A site for wastewater application should be a modified open system where provisions are made for the interception and removal of water after renovation.

In most landscapes, the surface soil is underlain by horizons or strata which are less permeable (Fig. 2.2) and which restrict water movement and renovative capabilities. Examples of less permeable subsurface and subsoil horizons are:

- finer textured B horizons (claypans)
- compaction pans (plowpans)
- fragipans (silt pans)
- dispersed subsoils (chemical pans)
- dense glacial till, shale, siltstone, and residuum overlying limestone
- duripans (silica-cemented hardpans)
- petrocalcic horizons (caliche or lime cemented hardpan)
- ironstone sheets.

Where these layers occur, much of the water moves down to the less permeable layer and then laterally downslope. Where slopes become more concave, or where the less permeable layer comes closer to the surface, seeps occur (Fig. 2.2).

Shaping of landscapes may cause some of the above conditions. At any proposed site requiring major shaping, the characteristics of the subsoil horizons should be carefully evaluated to determine the types of chemical and physical characteristics which may be exposed or brought closer to the surface during the shaping operation.

Soils on convex landscape positions or on steep slopes usually are well drained, well oxidized, thinner, and subject to erosion. Soils on concave landscape positions and on broad flats are often more poorly drained, less well oxidized, and deeper. Water and sediment from higher positions move to these low-lying landscape areas.

Soil and Parent Material

On land used for sludge and/or wastewater applications, the soil functions as a natural filter and as a medium for the biological and chemical reactions which result in renovation of these waste materials. The suitability of a site is therefore a function of the physical, chemical, and mineralogical characteristics of the soil. These are discussed in detail below:

Texture

Texture of the soil and parent geologic material is one of the most important aspects of site selection because it influences infiltration rate, subsoil percolation rate, moisture holding capacity, and adsorption reactions for waste components.

Fine textured soils include clay, sandy clay, silty clay, clay loam, and silty clay loam. Medium textured soils are silt, silt loam, loam, and sandy clay loam. Coarse textured soils include sand, loamy sand, and sandy clay loam. Definitions of textural terms can be found in the U.S.D.A. Soil Survey Manual (25).

In most soils, the clay fraction represents only about 10 to 40% of the total soil, but because clays are plate-shaped and have high surface areas, this component, along with organic matter, governs most physical and chemical reactions in the soil. These electrically charged particles have structures and properties which permit their large surface areas to hold various nutrients (including phosphates), heavy metals, and pesticides. Nitrate, on the other hand, is not held to these surfaces and is mobile.

Infiltration and Permeability

Fine textured soils often have as much pore space as coarse textured soils but pores in fine textured soils are very small and transmit water very slowly. As a result, most water movement in fine textured soils is along the surfaces of the soil aggregates and cracks rather than through the entire soil volume. When fine textured surface materials are wetted and the large transmitting channels closed, the infiltration rate becomes very slow. Percolation rate in the subsoil follows a similar pattern in medium and fine textured materials. Swelling of the clay fraction, particularly high shrink-swell clay minerals, effectively seals the soil against further downward movement of water. This sealing causes the water to pond on top of the subsoil which in turn favors runoff and erosion from the landscape. One should be cautious in evaluating a site for sludge application on fine textured soil to assure that the amount of water added will infiltrate. Failure to achieve rapid infiltration could result in temporary anaerobic conditions and increased risk of odors.

If poorly and imperfectly drained soils are to be used for renovation of wastewater by spray irrigation, drainage systems will be needed. These drainage systems should be placed at greater depths and at more frequent intervals than in normal agricultural drainage design. This will insure several feet of aerobic soil for normal crop growth and adequate wastewater renovation. If artificial drainage is provided, monitoring of drainage water should be undertaken for the first season to insure that the treatment system is performing as designed.

Recently there has been considerable interest in utilizing overland flow for wastewater renovation on fine textured soils where topography is favorable (see Section 8). Design criteria for determining both the percent and length of slope for proper renovation are still being developed.

In contrast to the fine textured soils, coarse textured soils have many large interconnecting pores which allow water to move rapidly through the soil. Unless the coarse textured material is underlain by a finer textured zone (such as a finer textured subsoil, pan, or parent material), water carrying suspended soluble components from sludges and wastewaters can move downward to the aquifer and may cause contamination of a public or private water supply.

If only coarse textured soils are available, improved renovation can be achieved by limiting the quantity of wastewater applied at any one time. This allows more time for plant uptake of nutrients and for the soil chemical and biological reactions important for renovation to occur. Under intensive management and proper conditions, wastewater renovation has also been achieved in coarse textured soils by the rapid infiltration-percolation method (5).

Infiltration and permeability rates tend to increase with increased organic matter content. Organic matter improves soil aggregation and porosity and allows water to be transmitted more rapidly. In addition, organic material in the surface helps prevent crusting, particularly in silty soils.

Biotic factors also contribute to variability in permeability. In areas which are forested or which have recently been cleared, old root channels permit water and potential pollutants to move through the surface soil more rapidly. Burrowing insects and animals also create channels. Following a heavy rainfall, water may move through the soils in these biotic channels rather than through the soil profile. This effectively reduces the renovative capacity of the soil.

Moisture Holding Capacity

Soil texture and bulk density (soil weight per unit volume) of the soil are important factors in determining the available moisture holding capacity. This capacity is a measure of the moisture a soil can hold for plant use. It also gives an index to the amount of moisture a soil can absorb. Medium textured soils with bulk densities of less than 95 $lb./ft.^3$ have available moisture holding capacities of 15 to 20%. Such soils, when dry enough that plants permanently wilt, will absorb 9 to 12 inches of water from sludge, wastewater, or rainfall in the upper 60 inches before transmitting water to the underlying aquifer. Finer and coarser textured soils have lower moisture holding capacities and thus would not retain as much water.

Bulk Density

In all soils, the moisture holding capacity and percolation rate decrease as bulk density increases. Additionally, plant root growth is limited in soils with high bulk densities. Bulk densities greater than 100 $lb./ft.^3$ are restrictive to moisture movement and plant root growth. Two common situations where these high bulk density values may occur are in fragipans and in unweathered glacial till. Often in the spring of the year, these very dense zones will limit vertical water movement to such an extent that water will be ponded above these horizons and a perched water table situation develops. Dense zones or horizons limit the thickness of the soil as a renovation medium, and favor anaerobic conditions above the pan when waterlogging occurs. Soil compaction and increased bulk densities may occur when sludge application equipment is used on excessively wet soils (see Section 5).

Soil Reaction

The glacial till and loess from which most of the soils of the North Central Region are developed were calcareous when deposited. As a result of leaching and soil development, carbonates have been removed from the surface. Soil reactions near neutral (pH values 6.5-7.5) are important for the immobilization of heavy metals and phosphates which occur in sludges and wastewaters. Most soils of the Western United States, since they have soil reactions near neutral, have suitable soil reactions to immobilize heavy metals and phosphates. Soils with low pH's (<6.5) must be amended with lime prior to applications of sludge to raise the pH. Medium textured soils with free carbonates at less than 4 or 5 feet are very effective in immobilizing heavy metals and phosphates which might move downward, particularly in a closed drainage system.

Restrictive Layers

Soils are not uniform either vertically or horizontally. In cross-section, the soil can be seen as a series of layers of differing permeability. A number of these layers in different soils are restrictive to water movement.

The most common restrictive layer is the horizon of clay accumulation (clay pan) which occurs in most upland soils. A second restrictive layer is the plowpan, or traffic pan, which may form 6 to 10 inches below the surface as a result of traffic of heavy equipment (either farm or construction) over the surface. Fragipans (silt pans) are a third type of restrictive zone resulting from natural soil-forming processes in silty or loamy materials. These compact pans start at depths of 15 to 40 inches and have bulk densities ranging from 95 to 125 lb./ft.^{3}.

A fourth type of restrictive zone is the dispersed subsoil situation or chemical pans. These restrictive layers result from the dispersion of individual soil particles so that the soil mass has lost most of its structural characteristics and water conducting channels. The main chemical responsible for the dispersion is sodium. Most soils with a major clay component of montmorillonite and a significant amount of sodium have restrictive layers.

A fifth type of restrictive layer is the result of dense parent material or bedrock such as glacial till, shale, siltstone, etc. Rock-like layers can also form as the result of precipitation of silica (duripans), carbonate (petrocalcic and calcic horizons), or iron (ironstone layers).

Soil Variability

In selecting any site for sludge and/or wastewater renovation, it is important to consider soil variability. Soils developed from loessial (wind-blown silt) materials are most uniform, while those derived from glacial outwash or interstratified bedrock materials are most variable. Glacial till may also be quite variable, particularly when in close proximity to glacial outwash deposits. The magnitude and type of soil variability may determine the suitability of an area for sludge and/or wastewater application and are important in determining the pattern and extent of sampling for site evaluation. On-site investigation of a proposed site is essential to determine the magnitude of soil variability. *Failure to do so could result in some unexpected environmental or management problems.*

Sampling

Within every soil series there is a given range in physical, chemical, and mineralogical properties. Soil analyses in Soil Survey Reports represent the central concept of the soil, but soils at a proposed site may have somewhat different characteristics. Therefore, it is highly recommended that analyses be made of the soils found at the site. Useful laboratory analyses include particle size, organic matter, pH, cation exchange capacity, moisture holding capacity, and bulk density. On-site evaluation should include the measurement of percolation, permeability, and water table levels at various times of the year. If clay mineralogy of the soils is not well documented, this analysis should also be made. In most of the Western United States and in the central and western portion of the North Central Region where high sodium levels are commonly found in the soils, electrical conductivity of the samples should also be determined. Soil samples from the actual site also provide base line data from which soil changes may be evaluated after sludge and wastewater application.

Available Resource Material

The preceding discussion has outlined a number of properties of the landscape, soils, and soil parent materials which are important in evaluating a site for sewage sludge and/or wastewater application. This discussion is not sufficient for making a final decision on site location. Many other resources of published material and personnel are available and should be consulted before a final decision is made. Some sources of qualified personnel were discussed on page 2.1.

Published reports on soils, geology, topography, and hydrology are available for most areas in the country. Emphasis is being placed on publication of more reports for areas undergoing urban expansion. Among the most useful standard reports available are the Soil Survey Reports produced by the National Cooperative Soil Survey and published by the U.S. Dept. of Agriculture. Each report contains a detailed map showing the areal distribution of soils in the area, along with physical, chemical, and mineralogical data and/or estimates for all the soils. In many areas, maps may be available even though the final report has not been printed. Often an interim report containing soil descriptions and data is available prior to the final report. A soils map is developed by soil scientists examining the entire area, and is useful for general planning purposes. It is not, however, detailed enough so that it can be used without on-site inspection by qualified personnel. In areas where a soil survey is not available, a soils map can be requested by contacting the local Soil Conservation Service office.

In some areas, geologic reports on a quadrangle base are available. These reports give details on the geologic strata in the area, including a map and discussion of surficial deposits. Some chemical and physical data on the various strata are also included in most of these reports. These reports are particularly useful in identifying aquifers and thus areas where sands, gravel, limestone, and other rapid conductors of water are located. Topographic maps of the 7-1/2 minute quadrangle series are available from the U.S. or State Geological Survey for most of the country. These maps show contour lines and cultural features, including roads, houses, and lakes. In many areas, special reports have been made on groundwater hydrology by the U.S. or State Geological Survey or by local groups interested in knowing the groundwater potential.

On-site inspection by trained professionals is a must for all sludge and wastewater application sites. The qualified soil scientist can provide the user with more detailed information on the limitations of the soils at the site and can identify areas of soils that differ from those delineated on a standard soils map accompanying Soil Survey Reports. Qualified soil scientists may be available at the local Soil Conservation Service office, the State Department of Natural Resources, the State Agricultural Experiment Station, or at local professional consulting firms. The Cooperative Extension Service usually has personnel in the county who can assist in determining suitable sites. Geologists should also be consulted in cases where installations are to be made to depths greater than 5-6 feet, or where there may be questions concerning a shallow or complex aquifer. Help from geologic consultants is available from the U.S. or State Geological Survey and professional engineering consulting forms.

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Section 3

ANALYSES AND THEIR INTERPRETATION for Sludge Application to Agricultural Land

Lee E. Sommers and Darrell W. Nelson

Sewage sludge is a general term used to describe a variety of materials, commonly a suspension containing 1 to 10% solids, produced during treatment of wastewater. Sludges generated during the secondary stage of wastewater treatment are normally "activated sludges." Solids separated from the wastewater during primary treatment (primary sludge) are subjected to anaerobic digestion, producing what is generally referred to as "sewage sludge" or "anaerobically digested sludge." In some treatment systems, both the primary and secondary sludges are digested anaerobically. In addition, a wet-air oxidation process is being used in some treatment plants rather than anaerobic digestion for stabilization of primary and/or secondary sludges.

Since "primary sludge" contains high concentrations of coliforms and other potentially dangerous pathogens, application of undigested "lime treated primary sludge" on land is sometimes recommended, but presents problems which aren't covered in this paper. In the future additional types of sludges may be applied to land. The use of lime or alum during tertiary treatment of wastewater will produce a tertiary sludge.

In general, the majority of sludge applied to land will be anaerobically and aerobically digested sewage sludge rather than other sludges. After digestion, sewage sludge may be further processed to reduce the water content by vacuum filtration or centrifugation, resulting in a sludge "cake" containing 30-40% solids. Due to economic and technical problems, the majority of sewage sludge will be applied to land as a suspension containing from 1 to 10% solids (*i.e.*, in the form exiting the digester or settling tank).

It should be realized that sewage sludge is a very heterogeneous material, varying in composition from city to city and from day to day in the same city. Thus, before a serious attempt is made to develop plans for sludge application to agricultural land, considerable thought should be given to obtaining representative samples and making arrangements for accurate chemical analysis of the sludge.

Sludge Analyses

Sample Collection

Preliminary analyses can be made from a single sample, but more detailed sampling is needed. For actual rate application determination, separate samples of the sludge should be collected once per 2-3 months for a period of 6 to 12 months in order to obtain a representative analysis of the material to be considered for land application. One liter (or qt.) of sample should be stored in a plastic or glass container so that evaporation of water is prevented. If dry sludge is used, these precautions are not necessary and a plastic bag will suffice for sample storage and transportation. Samples should be subjected to chemical analysis as soon as possible. If storage is required, it is recommended that samples be frozen or stored at 33-36° F. If more than 1 hour will elapse between sample collection and cold storage, enough hydrochloric acid should be added to slurry samples to bring the pH value to between 0 and 1.

Sludge Analysis

Sewage sludges contain a wide variety of materials, including plant nutrients, organic materials, oils, greases, and trace metals. The metal content of sludge is especially important because many metals are essential for plant growth at small concentrations, but are toxic at high concentrations. A complete analysis of sewage sludge is a very involved process requiring considerable effort. Fortunately, a complete analysis is not required to make a recommendation for rates of sludge application to agricultural lands. The sludge analysis recommendations which follow should be considered tentative since future information may indicate that additional elements should be included or that some of the elements included need not be determined.

Necessary Analyses

Analyses required of all sludge samples and the suggested analytical methods are shown in Table 3.1. Since the solids content of sludges varies from batch to batch, all composition data must be expressed on an oven-dry solids basis.

Additional Analyses

The following elements may be of concern in special instances, but in most sewage sludges which are encountered they will not influence the rate of application of sludge to land: selenium, cobalt, chromium, arsenic, boron, iron, aluminum, mercury, silver, barium, sulfur, calcium, magnesium, sodium, inorganic carbon, and organic

TABLE 3.1--Methods for Sludge Analysis.*

Parameter	Suggested Method
Percent solids	Drying at 105° C. for 16 hrs.
Total N (nitrogen)	Micro-Kjeldahl and S.D.†
NH_4^+-N (ammonium)	Extraction with potassium chloride and S.D.
NO_3^--N (nitrate)	Extraction with potassium chloride and S.D. after reduction
Total P (phosphorus)	Nitric acid-perchloric acid digestion and colorimetry
Total K (potassium)	Nitric acid-perchloric acid digestion and flame photometry
Copper (Cu), zinc (Zn), nickel (Ni), lead (Pb), and cadmium (Cd)	Nitric acid-perchloric acid digestion and atomic absorption‡

*References (4, 11, 20).

†S.D., steam distillation and titration of distillate with standard sulfuric acid.

‡Background correction (e.g., deuterium or hydrogen lamp) may be needed for cadmium and nickel.

carbon. (Refer to Section 11 for information qualifying the above list of elements.) With the exception of sulfur and carbon, all analyses listed above can be accomplished with atomic absorption spectrophotometry provided the sludge contains significant amounts of the element. In most cases the elements arsenic, selenium, boron, chromium, and mercury are of greatest importance in industrial wastes; however, some municipal sludges may contain elevated levels of these metals if industrial wastes are added to the sewage system. In these cases the industrial wastewater should be examined and based on this information a decision should be made as to which sludge parameter is of greatest concern. Even though some of the above elements may be present in high concentrations in sludge, they do not appear to limit crop growth to the extent of the elements listed under Necessary Analyses.

Considerations for Applying Sewage Sludge on Agricultural Land

The following information is needed prior to calculating the rate of sludge application:

- Sludge composition (see Table 3.1)
- Soil pH, cation exchange capacity, and lime requirement to adjust soil to pH 6.5
- Soil test for available P and K; P and K fertilizer recommendation for crop to be grown
- Crops to be grown.

The rate of sludge application to land is based on the nitrogen requirement of the crop grown and the metal content of the sludge. If the sludge being applied has a low metal content, then it is possible to use sludge as nitrogen fertilizer material. However, if the sludge contains high concentrations of metals (*i.e.*, Zn > 5000 ppm, Cu > 1000 ppm, Ni > 500 ppm, or Cd > 50 ppm, all on a dry weight basis, then the sludge may be used as a supplemental nitrogen source only. In either case it may be necessary to use commercial fertilizer materials to furnish potassium for crop growth. The ranges of nitrogen, phosphorus, and potassium contents found in anaerobically digested sewage sludges are shown in Table 3.2.

After addition to soil, sewage sludge is slowly decomposed, resulting in release of nitrogen available for plant growth. Available data suggest that 15-20% of the organic nitrogen is converted to plant available forms the first year and that 3% of the remaining organic nitrogen is released each year for at least three subsequent years. Thus, plant available nitrogen is released for several years after sludge has been added to soils. For example, decomposition of a sludge con-

TABLE 3.2--Composition of Representative Anaerobic Sewage Sludges.

Component	Range*	Lb./Ton†
Organic nitrogen	1% - 5%	20 - 100
Ammonium nitrogen	1% - 3%	20 - 60
Total phosphorus	1.5% - 3%	30 - 60
Total potassium	0.27% - 0.8%	4 - 16

*Percent of oven-dry solids.
†Lb./ton dry sludge.

TABLE 3.3.--Total Amount of Sludge Metals Allowed on Agricultural Land.

Metal	Soil Cation Exchange Capacity (meq/100 g)*		
	0 - 5	5 - 15	> 15
	Maximum Amount of Metal (Lb./Acre)		
Pb	500	1000	2000
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

*Determined by the ph 7 ammonium acetate procedure.

taining 3% organic nitrogen applied at 10 tons/acre/year for 3 years will release 41 lb. of nitrogen the fourth year. Thus, sludge application rates are based on the quantity of readily available nitrogen in sludge (*i.e.*, NH_4^+ and NO_3^-) and on the amount of nitrogen released during sludge decomposition in soil. Because of nitrogen losses from denitrification, ammonia volatilization, etc., nitrogen from sludge approximately equal to or 50% higher than the crop nitrogen requirement can be added to soils with minimal environmental risk. If sludge is incorporated immediately (*e.g.*, injected), then available nitrogen from sludge equal to the crop nitrogen requirement should be added. Although phosphorus toxicity to crops is not a problem in most cases, the level of available phosphorus in soils receiving sludge should be checked and serious consideration given to discontinuing sludge applications if available phosphorus exceeds 1500 lb./acre. The crop most susceptible to injury from excess phosphorus appears to be soybeans.

The criteria used to prevent metal injury from sludge application on land are based upon the total amount of Pb, Cu, Zn, Ni, and Cd added in sludges. Whereas nitrogen commonly limits the annual application rate of sludge, metals in sludge will determine the length of time a given acreage can receive sludge. The upper limit for metal addition is given in Table 3.3. In addition, to the maximum accumulation of Cd shown, the rates of sludge application should result in no more than 2 lb. of Cd per acre being applied on an annual basis.

These values are the total amounts of metals which can be added to soils. With metal contaminated sludges, one of the above criteria may be met with a single application, whereas 5, 10, or 20 applications may be needed for "clean" domestic sludges. Furthermore, when the metal limits are reached, sludge application must be terminated. A soil pH > 6.5 must be maintained in all sites after sludge is applied to reduce the solubility and plant uptake of these potentially toxic heavy metals.

Calculation of Annual Application Rate

Step 1. Obtain N requirement for the crop grown from Table 3.4.

Step 2. Calculate tons of sludge needed to meet crop's N requirement.

a. Available N in sludge
   % Inorganic N (N_i) = (% NH_4-N) + (% NO_3-N)

% Organic N (N_o) = (% total N) - (% inorganic N)

Lb. available N/ton sludge = (% N_i x 20) + (% N_o x 4)

b. Residual sludge N in soil

If the soil has received sludge in the past 3 years, calculate residual N from Table 3.5.

c. Annual application rate

i) Tons sludge/acre = $\frac{\text{crop N requirement - residual N}}{\text{lb. available N/ton sludge}}$

If sludge is surface applied, this rate can be doubled.

ii) Tons sludge/acre = $\frac{\text{2 lb. Cd/acre}}{\text{ppm Cd x .002}}$

iii) The *lower* of the two amounts is applied.

TABLE 3.4.--Annual Nitrogen, Phosphorus, and Potassium Utilization by Selected Crops.*

Crop	Yield	Nitrogen	Phosphorus	Potassium
		Lb. per Acre		
Corn	150 bu.	185	35	178
	180 bu.	240	44	199
Corn silage	32 tons	200	35	203
Soybeans	50 bu.	257†	21	100
	60 bu.	336†	29	120
Grain sorghum	8,000 lb.	250	40	166
Wheat	60 bu.	125	22	91
	80 bu.	186	24	134
Oats	100 bu.	150	24	125
Barley	100 bu.	150	24	125
Alfalfa	8 tons	450†	35	398
Orchard grass	6 tons	300	44	311
Brome grass	5 tons	166	29	211
Tall fescue	3.5 tons	135	29	154
Bluegrass	3 tons	200	24	149

*Values reported above are from reports by the Potash Institute of America and are for the total above-ground portion of the plants. Where only grain is removed from the field, a significant proportion of the nutrients is left in the residues. However, since most of these nutrients are temporarily tied up in the residues, they are not readily available for crop use. Therefore, for the purpose of estimating nutrient requirements for any particular crop year, complete crop removal can be assumed.

†Legumes get most of their nitrogen from the air, so additional nitrogen sources are not normally needed.

TABLE 3.5.--Release of Residual Nitrogen During Sludge Decomposition in Soil.

Years After Sludge Application	Organic N Content of Sludge, %						
	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Lb. N Released per Ton Sludge Added						
1	1.0	1.2	1.4	1.7	1.9	2.2	2.4
2	0.9	1.2	1.4	1.6	1.8	2.1	2.3
3	0.0	1.1	1.3	1.5	1.7	2.0	2.2

Step 3. Calculate total amount of sludge allowable.

a. Obtain maximum amounts of Pb, Zn, Cu, Ni, and Cd allowed for CEC of the soil from Table 3.3 in lb./acre.

b. Calculate amount of sludge needed to exceed Pb, Zn, Cu, Ni, and Cd limits, using sludge analysis data.

Metal

Pb: $\text{Tons sludge/acre} = \dfrac{\text{lb. Pb/acre}}{\text{ppm Pb x .002}}$

Zn: $\text{Tons sludge/acre} = \dfrac{\text{lb. Zn/acre}}{\text{ppm Zn x .002}}$

Cu: $\text{Tons sludge/acre} = \dfrac{\text{lb. Cu/acre}}{\text{ppm Cu x .002}}$

Ni: $\text{Tons sludge/acre} = \dfrac{\text{lb. Ni/acre}}{\text{ppm Ni x .002}}$

Cd: $\text{Tons sludge/acre} = \dfrac{\text{lb. Cd/acre}}{\text{ppm Cd x .002}}$

(Note: Sludge metals should be expressed on a dry weight ppm (mg/kg) basis.)

The lowest value is chosen from the above five calculations as the maximum tons of sludge per acre which can be applied.

Step 4. Calculate amount of P and K added in sludge.

Tons of sludge x % P in sludge x 20 = lb. of P added

Tons of sludge x % K in sludge x 20 = lb. of K added

Step 5. Calculate amount of P and K fertilizer needed.

(lb. P recommended for crop)* - (lb. P in sludge) = lb. P fertilizer needed (lb. K recommended for crop)* - (lb. K in sludge) = lb. K fertilizer needed

A sample calculation may be found in Appendix B.

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*P and K recommendations based on soil tests for available P and K.

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Section 4

CROP AND SYSTEM MANAGEMENT for Sludge Application to Agricultural Land

Robert H. Miller

The primary emphasis of this document has been the application of sludge to agricultural lands in a manner which will assure that no permanent damage is done to the land or to the environment. This is particularily important if the land receiving the wastes is leased rather than purchased and the farmer applies the sludge to his land as an alternate source of nutrients. If this approach is followed, the annual application rate will usually be based on nitrogen sufficiency for crop growth (see Section 3) and usually will be under 10 tons/acre. The long-term quantity of sludge applied to any one site will be based on the type and quantity of metals present in the sludge (see Section 3).

This section contains a number of considerations important for managing the farming operation when sludge is applied to land. As with so many other aspects of waste application to land, no one proposal can be recommended for all situations. The design and management of each site will be unique and require the coordinated efforts of the farmer and/or farm manager, the treatment plant operator, and agricultural engineers.

Management Considerations

Soil Management-Site Selection

Proper site selection prior to sludge application greatly simplifies soil management. These factors have been discussed previously in Section 2 and will be repeated only briefly before going on to other considerations.

Of primary importance to the success of the system is the establishment and maintenance of a pH >6.5. Most metals are less soluble at pH 6.5 than at lower pH values, and a pH >6.5 will restrict plant uptake and accumulation of metals as well as their downward mobility in the soil. Soils should be selected which have the desired pH or be limed until a pH of 6.5 or greater is attained. After sewage sludges are applied, soil pH should be evaluated annually to insure that the pH remains at or near pH 6.5. Oxidation of excess nitrogen to nitrate or sludge sulfur to sulfate could lower the soil pH. Other soil properties influencing the chemistry and availability of metals in soils include the cation exchange capacity (see Section 3 and the influence of cation exchange capacity on maximum total sludge application rate), the soil organic matter content, the presence of hydrous oxides of iron, aluminum, and manganese, and the phosphorus content.

Soil drainage characteristics, which are influenced by a myriad of factors (Section 2), are also important because they influence the timing and method of sludge application, as well as tillage, planting, and harvesting operations after sludge additions.

Soil Management-Fertility Considerations

The nitrogen in anaerobically digested sewage sludge usually consists of about one-third ammonium. Other sewage sludges also contain significant concentrations of ammonium nitrogen. The most commonly employed method of sludge application is on the soil surface, after which it may or may not be incorporated. If the sludge is allowed to dry on the soil surface, considerable ammonia is volatilized into the atmosphere. The actual amount lost will depend on the nature of the soil, soil water content, quantity of sludge applied, and the sludge itself. It has been estimated that 25-50% of the ammonium will be lost if sludge is applied on the surface. If the sludge is injected directly into the soil or incorporated into the soil immmediately after surface application, most of the ammonium will be retained.

Sewage sludges generally contain considerably more phosphorus relative to the nitrogen needs of most crops. Sludge applications based on the nitrogen requirements of the crop may often over-fertilize with respect to phosphorus. Unless very high amounts of sludge are applied, however, the soil will immobilize excess phosphorus rapidly and over-fertilization should not present problems for many years. However, in one experiment in Illinois, the application of a very high amount of sewage sludge in a single year resulted in phosphorus toxicity to soybeans.

Sewage sludges are usually very low in potassium, a value of about 10 lb. of potassium per ton of dry sludge being common. Other cations in the sludge will often compete with potassium in the soil solution and restrict potassium uptake by plants. Thus, no credit should be given to even the low amount of potassium in sludges and the soil should be fertilized with potassium according to the results and recommendations of soil tests.

Soil Management-Runoff Control

Sewage sludge applied to the surface of the soil without immediate incorporation can be transported in runoff waters and result in contaminated surface waters. The potential danger of runoff increases greatly on sloping land in regions of high rainfall and is the reason that soils to be used for sludge application should be restricted to those with less than 6% slopes wherever possible. (See Section 2.) The dangers are most severe if an intense rain occurs soon after liquid sludge is spread on sloping land. Methods of application other than surface application must be considered where sloping land is employed. Diversions or earthern barriers may also be necessary to contain runoff temporarily, and prevent sludge from reaching water courses. These latter considerations are all facets of engineering design.

Regardless of slope, certain conservation practices can be adopted which will minimize runoff from sludge-treated soils. Such practices include reduced tillage systems, terraces, strip cropping, and retention of crop residues on the soil surface wherever possible.

Crop Selection

Crop selection is not an important management consideration in systems where the sludge application rate is based on nutrient needs, or restricted to minimize potential damage by heavy metals. The farmer or farm manager has available almost all of the common agronomic crops.

With no limitations in the selection of plant species, it is usually advantageous to maintain or utilize the normal cropping patterns found in the community. These patterns have usually evolved because of favorable soil, climatic, or economic reasons and will probably maintain certain advantages in the sludge application system as well. One possible exception could occur if the cropping pattern of the area is restricted largely to a single crop. Here there could be advantages in employing an additional crop or crops to increase the opportunity of applying sludge during a variety of seasons. A simple example would be a corn monoculture system vs. a corn and grass forage rotation. In the latter system, sludge can be applied to corn land and incorporated prior to planting and after harvest. Additional surface applications could be made on some soils of the North Central Region throughout the winter months, subject to local or state regulations, when not frozen or covered with ice or snow. The forage component would allow sludge applications to land at those times when the corn land would be inaccessible, *e.g.*, when too wet for trafficability.

Timing of Operations

Timing of sludge applications to land as well as all the farming operations of the system are dependent on climate, soil properties, the crop, and the tillage, planting, and harvesting procedures employed.

Climate has a major influence on management of soils and crop systems receiving sludge. Temperature has a direct influence on application of sludge in areas where frozen soils or snow cover make sludge applications impractical or environmentally unsound. In northern areas of the U.S., winter storage facilities for wastes are required and increase the operation costs for the municipality. Temperature also influences the growing season of plants and the rate of decomposition of sludge organics in soil. Both of these factors influence the renovative capability of the soil. The mean length of the freeze-free period in days (growing season) varies greatly within the North Central Region from about 100 days along the Canadian border to about 200 days in the southernmost states of the region. The freeze-free period varies from 150 to 180 days in most of the Corn Belt. Useful temperature data for the North Central Region can be found in N.C. Regional Publication No. 174 (9).

Rainfall has an influence on all management decisions involving sludge application, tillage, planting, and harvesting. Care must be exercised to assure that sludge is not applied to wet soils with heavy equipment. Such applications would result in compaction and reduction in crop yields. Rainfall distribution also influences the amount of sludge storage required by a municipality. If the soils are too wet for sludge application at the planned or desired time, the farmer may not be able to accept the sludge as planned. Storage would thus be required until conditions are again favorable for applications to continue.

Soil properties are extremely important to scheduling sludge application as well as determining the ease and timeliness of all tillage, planting, and harvesting operations. Applying sludge to land by almost all methods is an additional operation of concern to the farmer as well as the treatment plant. Delays for the farmer may mean a disruption of his normal tillage and planting operations, and may be economically unacceptable. Unfavorable soil properties, *e.g.*, high water table, saturated soils, etc., also mean that sludge cannot be applied in the Spring of the year and reduce the acceptability of land application for a municipality which must have the capability for all-season application. Likewise, delays in harvesting because of wet soils might limit Fall application of sludge with the same result. Thus it is very important that soils be chosen which are well enough drained to produce a minimum delay for all important operational procedures of the system.

The choice of crop or crops provides a means by which the farmer as well as the treatment plant operator can vary the time periods during which sludge can be applied to land. These aspects have been discussed briefly under Crop Selection. Some flexibility in sludge application can also be provided by altering the maturity dates of small grains, corn, or sorghum cultivars so that harvesting, tillage, and planting operations can more nearly fit the climatic or soil limitations on sludge application discussed previously.

Other Management Considerations

There are some data showing that sludge can retard seed germination and early plant growth. Most of these cases have occurred at sludge application rates higher than those recommended here. The retardation is thought to be caused by a high concentration of soluble salts and/or high ammonia contents. These problems can be further reduced by applying the sludge 2 to 3 weeks before planting, by thorough mixing of the sludge in the tilled soil layer, or by a thorough irrigation prior to planting. In the humid regions of the U.S., the problem will be potentially less severe than in the more arid non-irrigated regions.

Herbicide applications for weed control on soils receiving sludge should be the same as those normally used for a particular crop or soil. Weed control is especially important because of a desire to maximize crop yields and nutrient removal. An additional weed problem may arise because tomato seeds survive waste treatment and grow profusely in sludge-treated soils.

In general, the use of other pesticides on sludge-treated soils will not be altered from the normal procedure recommended for untreated soils.

Sewage sludges should not usually be applied directly on leaves of growing plants unless the sludge solids can be subsequently washed off by irrigation water. Liquid sludge when applied on leaves of plants will dry and coat the leaves, reducing photosynthetic activity. Observations from studies in Illinois have indicated that corn yields will be reduced if the leaves are coated with sludge repeatedly during the growing season. If desired, liquid sludge can be applied to row crops during the growing season by gravity irrigation techniques, by tank wagons, or by overhead irrigation systems equipped with drop hoses between rows.

Sludges can be applied to forage crops during the season if applied prior to spring growth, after dormancy, or immediately after cutting and before significant new growth has begun.

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Section 5

SELECTION OF THE SYSTEM for Sludge Application on Agricultural Land

Richard K. White

System and equipment considerations are the major engineering inputs to a workable operation of renovating municipal sludges by land application. What are the criteria which need to be considered in designing an acceptable system? The criteria should meet the following: no detrimental impact on the environment (air, water, or soil), while using the best available equipment to handle and apply the sludge on the land, in an economical manner, with good management practices such as uniform application and minimum nuisance.

Three phases in the handling of sludges for land disposal are interdependent: treatment (storage), transport, and application. The degree of treatment will affect the mode of transportation, *e.g.*, vacuum filtered sludge will need to be hauled as a solid. Partially stabilized sludge will need to be incorporated into the soil to avoid nuisance. A vital part of the total handling system is storage to allow for periods when application to the soil may not be possible, *e.g.*, freezing weather or soft ground.

Once the decision is made that the sludge will be handled as a slurry (liquid), semi-solid, or solid (cake), the type of transportation and application equipment can be selected. Table 5.1 indicates a range of solids content and handling characteristics. In the following sections on Transport and Application, systems and equipment will consider both liquid and semi-solid or solid sludges. One additional consideration, without respect to the sludge being in the liquid, semi-solid, or solid form, is whether soil incorporation is needed to prevent odor nuisance or surface runoff.

Transport

The selection of the transportation systems and equipment should consider the sludge production rate; *i.e.*, quantity, distance to site, proximity of application area to waterway, railway, or highway, whether application will be seasonal or year-

TABLE 5.1.--Sludge Solids Content and Handling Characteristics.

Type	Solids Content	Handling Methods
Liquid	1-10%	Gravity flow, pump, tank transport
Semi-Solid ("wet" solids)	8-30%	Conveyor, auger, truck transport (water-tight box)
Solid ("dry" solids)	25-80%	Conveyor, bucket, truck transport (box)

round, and the life of the application area. Table 5.2 lists alternate modes of transport for both liquid and solid sludges.

For large cities, *i.e.*, large quantities of sludge, the use of a pipeline, barge, or rail tank car may be the best choice from an economical and management viewpoint. The use of a truck which provides flexibility often is the best choice for a smaller community. If hauling distances are long, it may be best to use tank trucks for hauling over the highway and transfer to either a high flotation tank truck or tank wagon for field spreading. If year-round application by truck or tank wagon is selected, the use of flotation tires is necessary to allow field travel over soft ground. The use of tank trucks provides flexibility in locating land application areas, scheduling hauling, and enabling direct application, soil conditions permitting.

TABLE 5.2.--Transport Modes for Sludges.

Type	Characteristics
LIQUID SLUDGE	
Rail Tank Car	100 wet tons (24,000 gal.) capacity; suspended solids will settle while in transit.
Barge	Capacity determined by waterway; Chicago has used 1,200 wet tons (290,000 gal.) barges.
Pipeline	Need minimum velocity of 1 fps to keep solids in suspension; friction decreases as pipe diameter increases (to the fifth power); buried pipeline suitable for year-round use.
Vehicles	
Tank Truck	Capacity--up to maximum load allowed on road. Can have gravity or pressurized discharge. Field trafficability can be improved by using flotation tires.
Farm Tank Wagon and Tractor	Capacity--800 to 3,000 gallons. Principal use would be for field application.
SEMI-SOLID OR SOLID SLUDGE	
Rail Hopper Car	Need special unloading site and equipment for field application.
Truck	Commercial equipment available to unload and spread on ground; need to level sludge piles if dump truck is used.

Commercial tank trucks are available from companies handling equipment for sewage and sludge handling and for livestock manure handling. Gravity discharge from the tank truck is most common. The rate of discharge and the area of application can be increased by using a pressurized tank or a pumped discharge.

Storage

At some point in the system for handling sludge, storage will need to be provided. It can occur at the treatment facility or at the land application site. Except for large cities which may have limited space at the treatment facility, it would normally be best to provide storage at the treatment facility. This storage is necessary so that the transportation will not be hindered by fluctuations in the sludge output. Storage is also necessary if a breakdown occurs in the transportation, or weather and soil conditions at the application area prevent immediate application. Storage may be provided in the digester or aeration tanks for a short time. For longer term storage, a tank or lagoon is normally used. Public acceptance of storage tanks or lagoons at the treatment site is better than at the application site.

Settling of suspended solids has been a problem in sludge storage units and in tanks when hauling liquid sludge over long distances. The agitation of sludge in storage units is necessary before transporting. It is best to minimize the number of storage events in the handling system.

Application

The criteria for selection of application systems and equipment are dependent upon several factors: the form of the sludge (liquid, semi-solid, or solid), the quantity, the areal application rate, whether a yearly application to the same area or one application in several years, whether seasonal or year-round application, topography of the area, and time of year. To prevent runoff, some states may require berms and/or diversions to be formed, requiring land shaping.

Two modes of application are surface or subsurface (soil incorporation). The latter may be required to control odors of partially digested sludge. If large quantities of digested sludge are being applied, soil incorporation may be necessary for a good public image. Table 5.3 indicates methods and equipment which can be used for surface or subsurface application of liquid and semi-solid sludges.

Surface application may be done by two general methods--irrigation or tank vehicle. Experience has indicated that a fixed irrigation system, in lieu of using portable pipe, is easier to manage. Because of this, irrigation will be better suited to a system which applies sludge regularly. It is possible to include sludge with a treated wastewater irrigation application system. An irrigation engineer (agricultural engineer) should be consulted to design the irrigation system.

Communities of 10,000 to 15,000 population have utilized tank trucks to apply their sludge on farmland. The tank truck provides flexibility in when to haul and where to apply the sludge. Year-round application can be performed by selecting sodded fields for application during wet conditions. The use of a pumped discharge on the tank (commercially available) will allow discharge over a wider area or from a roadway, which may be important in an emergency.

If there is the possibility of public nuisance from sludge application, and for greater nitrogen use efficiency, soil incorporation should be designed into the application system. For special conditions or at particular seasons of the year,

TABLE 5.3.--Application Methods and Equipment for Liquid and Some Semi-solid Sludges.

Method	Characteristics	Topographical and Seasonal Suitability
SURFACE APPLICATION		
Irrigation		
Spray (Sprinkler)	Large orifice required on nozzle; large power and lower labor requirement; wide selection of commercial equipment available; sludge must be flushed from pipes when irrigation completed.	Can be used on sloping land; can be used year-round if the pipe is drained in winter; not suitable for application to some crops during growing season; odor (aerosol) nuisance may occur.
Ridge and furrow	Land preparation needed; lower power requirements than spray.	Between 0.5 and 1.5% slope depending on percent solids; can be used between rows of crops.
Overland flow	Used on sloping ground with vegetation with no runoff permitted; suitable for emergency operation; difficult to get uniform areal application.	Can be applied from ridge roads.
Tank Truck	Capacity 500 to more than 2,000 gallons; larger volume trucks will require flotation tires; can use with temporary irrigation set-up; with pump discharge can spray from roadway onto field.	Tillable land; not usable with row crops or on soft ground.
Farm Tank Wagon and Tractor	Capacity, 500 to 3,000 gallons; larger volume will require flotation tires; can use with temporary irrigation set-up; with pump discharge can spray from roadway onto field.	Tillable land; not usable with row crops or on soft ground.

TABLE 5.3.(continued)--Application Methods and Equipment for Liquid and Some Semi-solid Sludges.

Method	Characteristics	Topographical and Seasonal Suitability
SURFACE APPLICATION		
Flexible irrigation hose with plow furrow or disc cover	Use with pipeline or tank truck with pressure discharge; hose connected to manifold discharge on plow or disc.	Tillable land; not usable on wet or frozen ground.
Tank truck with plow furrow cover	500-gallon commercial equipment available; sludge discharged in furrow ahead of plow mounted on rear of 4-wheel-drive truck.	Tillable land; not usable on wet or frozen ground.
Farm tank wagon and tractor		
Plow furrow cover	Sludge discharged into furrow ahead of plow mounted on tank trailer--application of 170 to 225 wet tons/acre; or sludge spread in narrow band on ground surface and immediately plowed under--application of 50 to 125 wet tons/acre.	Tillable land; not usable on wet or frozen ground
Subsurface injection	Sludge discharged into channel opened by a tillable tool mounted on tank trailer; application rate 25 to 50 wet tons/acre; vehicles should not traverse injected area for several days.	Tillable land; not usable on wet or frozen ground.

TABLE 5.4--Methods and Equipment for Application of Semi-solid and Solid Sludges.

Method	Characteristics
Spreading	Truck-mounted or tractor-powered box spreader (commercially available); sludge spread evenly on ground; application rate controlled by over-the-ground speed; can be incorporated by discing or plowing.
Piles or windrows	Normally hauled by dump truck; spreading and leveling by bulldozer or grader needed to give uniform application; 4 to 6-inch layer can be incorporated by plowing.
Reslurry and handle as in Table 5.3	Suitable for long hauls by rail transportation.

soil incorporation can be omitted; *e.g.*, cold weather or land areas located far from residences. Soil incorporation will require a larger power unit to perform both tillage and application simultaneously.

Where equipment is currently available at the waste treatment facility to dewater the sludge into a cake, land application in a solid form may be the best option. If the sludge has to be transported a long distance, economics may dictate dewatering. Table 5.4 presents methods and equipment for applying sludge to the soil in the solid form. The spreading method would generally be preferred over the piling or windrowing so that normal farm tillage operations and cropping can follow.

It is important to consider the land application of sludges as part of the total treatment system. This means that not only is the selection and use of suitable equipment important, but also management of the total land application system once it is operative. In fact, without good management the system will not function.

A review of the methods and equipment noted in this article will give a basis for selection of land application system components as well as specific types of equipment.

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Section 6

ANALYSES AND THEIR INTERPRETATION for Wastewater Application on Agricultural Land

Boyd G. Ellis

Wastewaters may be generated by municipal, agricultural, or industrial waste treatment facilities. Because of the nature of their origin, wastewaters are quite variable and as such offer a great challenge to the analyst. Variation in data may occur because of the method utilized in obtaining the sample or from laboratory to laboratory due to the use of different procedures. Recommendations made here should be considered as the procedure(s) that will produce the most uniformity in data and not as the only method possible or even the best method in some cases.

Sample Collection

The most critical stage in analysis of wastewaters is generally in obtaining a representative sample. Individual analyses require one liter (or qt.) or less which represents a very small part of the total flow into or out of a waste treatment facility. For this reason, it is recommended that the minimum be 10 equal volume grab samples obtained over a 2-day period and composited to give a single sample for analyses. The ideal and common system involves automatic samplers which take samples in proportion to flow for longer periods of time. More detail on sampling is contained in North Central Regional Publication No. 230 (20).

Preservation of samples without some change in chemistry is almost impossible; consequently, analyses should be completed as soon as possible after the sample is obtained. To keep changes in the sample to a minimum during storage, the guidelines by the U.S. Environmental Protection Agency (11) or American Public Health Association (1) should be followed. It is important to note that a single method of preserving samples is not adequate for all analyses.

Wastewater Analyses

Analyses which are recommended in all cases prior to application of wastewater to land are given in Table 6.1. Other analyses should be made if the presence of certain materials (*i.e.*, heavy metals) is suspected in the particular wastewater. Generally, a knowledge of the source of the wastewater is sufficient to identify the analyses that should be made. Many of the procedures recommended are published in Methods for Chemical Analysis of Water and Waste (11). Other alternative methods are found in Guidelines for Planning and Conducting Water Quality Experiments, a joint report of NC-12 and NC-98 (19) and Sampling and Analysis of Soils, Plants, Waste Waters and Sludges: Suggested Standardization and Methodology, a publication of NC-118 (20).

As in all analyses, analytical procedures should be constantly checked in each laboratory by the use of carefully prepared standards which match the matrices of the samples being analyzed and by cross-checking with standard samples exchanged between laboratories.

Interpretation of Data

Any of the parameters listed in Table 6.1 may limit the quantity of wastewater that may be applied to a particular site. In general, the parameters most likely

TABLE 6.1--Recommended Analyses and Procedures for Wastewaters to be Used in Wastewater Application to Agricultural Land.

Parameter	Recommended for Analysis	References
BOD_5	Yes	EPA (11)
COD	Yes	EPA (11)
% total solids	If suspected to be high	EPA (11)
Conductivity	If high soluble salts are suspected	EPA (11); USDA Handbook 60
pH	Yes	EPA (11)
Total N (nitrogen)	Yes	EPA (11); Black (4)
NO_3^--N (nitrate)	Yes	EPA (11)*
NO_2^--N (nitrite)	Yes	EPA (11)
NH_4^+-N (ammonium)	Yes	EPA (11); Black (4)
Total P (phosphorus)	Yes	
Soluble orthophosphate	If total P is high	EPA (11)
Cl^- (chloride)	If conductivity exceeds 250 μm/cm at 25° C.	EPA (11)*
K^+ (potassium)	If conductivity exceeds 250 μm/cm at 25° C.	EPA (11); Black (4)
Ca^{2+} (calcium)	If conductivity exceeds 250 μm/cm at 25° C.	EPA (11)
Mg^{2+} (magnesium)	If conductivity exceeds 250 μm/cm at 25° C.	EPA (11)
Na^+ (sodium)	If conductivity exceeds 250 μm/cm at 25° C.	EPA (11)
Heavy metals	If source of wastewater includes heavy metals	
B (boron)	Municipal effluents and if suspected in others	EPA (11)
Pesticides	If suspected	FWGPM† (1975)
Industrial organics	If suspected	EPA (22)

*Electrode methods may be used if the quantity is greater than 10 ppm N as NO_3^- or 10 ppm Cl^-.

†Federal Working Group on Pest Management. 1975. Guidelines on Analytical Methodology for Pesticide Residue Monitoring, Pesticides Monitoring Journal. U.S. Government Printing Office.

to influence the short-term performance of a land application system are water, suspended solids, readily decomposed organics (BOD_5), nitrogen, and total salt. Parameters which may be critical in limiting the numbers of years a particular system may be used include phosphorus, heavy metals, and industrial organics. A discussion of individual parameters follows.

Water

Water is a natural resource which may be utilized for crop needs (*i.e.*, applied at low rates, less than 20 inches per year) or it may be renovated by its association with the soil and the biological environment at considerably higher rates (*i.e.*, 60 or more inches per year). The soil may pose definite limitations upon the quantity of water which may be applied. (For a discussion of this aspect, see Sections 2 and 7.)

Suspended Solids and BOD

Suspended solids and BOD are generally low in secondary effluents but may be quite high in wastewaters from canneries or other industries which process agricultural or forest products. Infiltration capacity can be lost by sedimentation and slime formation if suspended solids and BOD loadings exceed the respiratory capacity of microbial populations which decompose organics filtered out at or near the soil surface. If the soil system is overloaded with BOD, anaerobic conditions will develop, and severe odor and insect problems can result. At moderate rates of application, the readily decomposed organics which give rise to BOD can augment the vegetative cover in supplying energy for denitrification and structural carbon for immobilizing nitrogen and other pollutants.

Nitrogen

Nitrogen in the nitrate form is the critical form of nitrogen because of its solubility and mobility in water, its stability in groundwaters, and its implications for eutrophication and for human and animal health. The other mineral forms of nitrogen are ammonium and nitrite. All three are readily taken up by plants. Ammonium and nitrite are converted (nitrified) quickly to nitrate in moderately well-aerated soil. Under poorly aerated conditions and in the presence of rapidly decomposing organic matter, nitrate and nitrite are reduced (denitrified) to gaseous forms which recycle back into the atmosphere. Both nitrification and denitrification are biological processes carried out by microorganisms which are not very active at temperatures below 50° F.

As much as one-third of the organic nitrogen applied in wastewater may be released (mineralized) as ammonium and nitrified to nitrate the first year. The remainder will be retained (immobilized) in residual humus. The humus will continue to decompose and release mineral forms of nitrogen and other nutrients in subsequent years, but at very much reduced rates. The rates of initial and residual release are reduced in the presence of rapidly decomposing carbonaceous materials (BOD) which may be added as wastes or supplied by roots and surface trash from the vegetative cover.

In overland flow systems, nitrogen may not be a critical loading parameter since the objective, frequently, will be to obtain partially renovated water for intermediate use rather than for discharge. In low rate irrigation systems, inputs of nitrogen should not exceed the capacity of the vegetation to take it up, plus some allowance for denitrification and immobilization. If no crop is to be harvested, some arbitrary limit--perhaps no more than 50 lb. per acre per year--should be set initially and adjusted as indicated by monitoring experience.

If crops are harvested, annual inputs of nitrogen should not exceed by more than 50% the anticipated harvest removal at yield goals which past experience indicates can be attained on similar soils with good management (see Section 7). This quantity is a function of both concentration and rate of application. An example calculation is given below:

Problem: Wastewater with 12 ppm N as NH_4^+ and 8 ppm N as NO_3^- is to be applied to a corn crop with an expected yield of 150 bu./acre.

Question: How many acre inches of wastewater may be applied during the growing season?

Calculation: 150 bu. of corn will remove approximately 125 lb./acre of N; therefore, no more than 125 x 1.5 = 187.5 lb. of N may be applied.

1 acre inch = 226,512 lb. of water.

Therefore, $\frac{226,512}{1,000,000} \times 20$ ppm N = 4.53 lb. N/acre inch.

$$\frac{187.5 \text{ lb. N}}{4.53 \text{ lb. N/acre inch}} = 41.4 \text{ acre inches of wastewater maximum.}$$

Little nitrate removal is expected during periods when actively growing vegetation is not present. Consequently, any level of nitrate exceeding 10 ppm nitrogen would be considered a serious hazard in wastewaters applied to barren land. The use of cover crops might well extend the successful application season on many treatment sites.

High Rate

Nitrogen application rates for high rate infiltration percolation systems are dependent upon the magnitude of denitrification and dilution within the aquifer. These parameters will be highly site dependent and cannot be discussed in a generalized manner.

Phosphorus

Phosphorus may be a key element for the success of a land treatment system when viewed over the long term. It can be utilized by crops and adsorbed or precipitated by the soil. Both total phosphorus and soluble orthophosphate determinations are necessary for proper interpretation of data from wastewaters which are to be applied to land. Within a few days (or weeks), all of the applied inorganic condensed phosphates should be converted to soluble orthophosphate. Organic phosphorus may be mineralized more slowly, but should be retained by the soil until converted to orthophosphate. If the conversion to soluble orthophosphate occurs, wastewater may be applied even without an actively growing crop with little danger of immediate loss to the drainage water. The phosphorus will be adsorbed by the soil and a portion of it will subsequently be removed by cropping. Soils from each particular site should be examined with respect to their ability to adsorb phosphorus.

Due to limited contact between wastewater and soil in overland flow systems, phosphate is inefficiently removed and runoff may not be of a quality that can be directly discharged into surface waters.

TABLE 6.2--Maximum Rates of Wastewater Application Related to Soil Texture and the Ability of the Soil to Adsorb Phosphorus.*

Soil Textural Group	Rate of Application
	acre inches/year
Silty clay to clay	60
Clay loam	55
Loam	53
Sandy loam	40
Loamy sand	45
Sand	40

*Assume 7 ppm total phosphorus in the wastewater and a crop removal of 25 lb. phosphorus/acre/year, with a 50-year expected life of the system. Data from Michigan soils.

Soluble Salts

Soluble salts generally will not accumulate in the soils of the North Central Region since precipitation surpluses in Fall, Winter, and Spring will remove salts by leaching. This is not true in the arid or semi-arid areas of the United States. In local situations, salts from special industries or from use on city streets may give rise to abnormal concentrations in sewage or storm waters. Further concentration of salts occurs in soils by evapotranspiration. In soils which do not transmit rainfall and irrigation water rapidly enough to keep salts moving downward through the root zone, salt injury to sensitive crops can occur if wastewater containing more than 1250 ppm dissolved solids (electrical conductivity about 2.0 mmhos/cm) is applied regularly during the summer months.

Sodium Adsorption Ratio (SAR)

Sodium adsorption ratio (SAR) may be an important consideration in the use of wastewaters even though Na (sodium), K (potassium), Ca (calcium) and Mg (magnesium) are not frequently a problem in wastewaters. A calculation of SAR values should be made according to the following equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

An example of this calculation for a typical wastewater is shown below:

Problem: A wastewater is found to have 150 ppm Na, 75 ppm Ca, and 20 ppm Mg.

Question: What is the SAR for this effluent?

Calculation:

$$SAR = \frac{\dfrac{150 \text{ mg Na/l}}{23 \text{ mg/me Na}}}{\sqrt{\dfrac{\dfrac{75 \text{ mg Ca/l}}{20 \text{ mg/meCa}} + \dfrac{20 \text{ mg Mg/l}}{12 \text{ mg/me Mg}}}{2}}} = \frac{6.522}{1.64} = 3.97$$

Wastewaters with SAR values greater than 15 should be avoided because of their detrimental effect on soil structure and ultimate reduction in the infiltration rate of the soils. Sodium adsorption ratio values from 5 to 15 can, over a period of years, lead to loss of structure in soil horizons containing more than 10 or 20% clay (loam or finer texture). Lower values are generally satisfactory, although long term declines in infiltration and percolation capacities have been observed in moderately fine-textured soils when irrigated with water having SAR ratios as low as 3.

Micronutrients

Micronutrients and metals are expected to accumulate in the sludge and not in the wastewater. Boron is a notable exception to this. It is likely to remain in the wastewater and move with the soil water. The toxicity of boron is related to plant species, with the most sensitive crops showing toxicity at 0.5 mg. B/l. Semi-tolerant crops may show toxicity for levels of 1 mg. B/l. or greater. In some soil situations, plants may actually benefit from low concentrations of boron in wastewater. The same may be true for iron, manganese, and zinc.

Organic Compounds

Organic compounds are found in wastewaters. Pretreated wastewaters contain natural products of partial decomposition and resistant synthetic compounds which have detergent or chelating properties and can enhance the mobility of potentially toxic trace organics and metals. Known organic toxicants which persist in wastewaters from conventional sewage treatment include a number of pesticides, chlorinated plasticizers, fire retardants, and other industrial chemicals. Most are strongly adsorbed by soils and are subject to slow decomposition or alteration to harmless products. They may pose an environmental hazard in special situations, particularly if water is allowed to percolate too rapidly through the soil. Sources of such chemicals should be identified and regulated to avoid excessive concentrations in wastewater that is to be applied on land where discharge into streams or lakes might occur.

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Section 7

CROP AND SYSTEM MANAGEMENT for Wastewater Application to Agricultural Land

Arthur R. Wolcott and Ray L. Cook

Land application may be viewed as an alternative treatment method or as an intermediate use for wastewater at a stage of renovation which cannot be discharged directly into surface streams or lakes. The two views do not oppose but support each other. The need to remove nitrogen and phosphorus from wastewater presents the opportunity to use these and other waste nutrients to upgrade natural landscapes or to support production of economic crops. In turn, beneficial responses of vegetation to added water or nutrients can contribute to the cost effectiveness of treatment.

The choice of land application as a method for treating wastewater will be influenced by public policies and attitudes, funding incentives, and regulatory constraints which are described in other sections in this publication. Considerations in site selection and system design also are dealt with in other sections. In this section, factors which should be considered in selecting vegetative covers and principles for management of wastewater application sites are discussed.

Selection of Vegetative Cover

The selection of vegetation to receive wastewaters cannot be considered independently of the selection of site or design approach. Consideration must be given to the hydraulic capabilities of soils and terrain in relation to natural hydrologic systems or to hydrologic systems which can be imposed on the site by engineering. Climate will influence decisions regarding site, design approach, and vegetative cover. Economic or other advantages associated with a given type of vegetation or a given resource management system must be considered as well.

Influence of Water Application Method

The widest latitude in choice of vegetative cover is afforded by low-rate irrigation (2 to 8 ft. per year). Low-rate irrigation on moderately permeable soils and slopes of 0 to 6% has the greatest potential for environmental benefit and economic return of any design approach. Options for vegetative cover and resource management systems range from public and private landscaping, greenbelts, wildlife habitats, or commercial forest plantings to agricultural and horticultural crops. Perennial or annual species can be considered, including intertilled crops.

In the case of crops grown for food or feed, the application of wastewaters which originate in livestock operations or municipal sewage systems will be closely regulated by state health authorities and marketing agencies. Restrictions on use of wastewater will vary with the crop and from state to state.

For effective renovation by low-rate irrigation, the wastewater must enter and percolate through 3 to 4 ft. of the soil profile. This approach may not be feasible on slowly permeable soils which will not accept and transmit at least 2 ft. of water per year. On such soils, substantially renovated water can be obtained by overland flow.

With suitable engineering, numerous crops can be grown in overland flow systems. On grass or forest cover, as much as 20 ft. or more of wastewater can be applied annually.

Vigorous, water-tolerant grasses which form dense sods are ideal for high rates of application. Reed canary grass (*Phalaris arundinaceae* L.) and tall fescue (*Festuca elatior* L., var. *arundinaceae*) appear most promising under climatic conditions in the North Central Region. Reed canary is slow to establish itself from seed. An established grass in old fields in many cutover areas is quackgrass (*Agropyron repens* L.). Quackgrass rivals reed canary in production of tough, interlacing rhizomes to bind the soil and carry heavy equipment.

All three of these grasses are highly productive under continuously moist conditions. However, they lose palatability rapidly as they approach maturity and must be cut two to four times a year to produce hay or silage acceptable to livestock.

A more palatable grass adapted to moist conditions is timothy (*Phleum pratense* L.). This is a bunchgrass, not a sod former. Improved strains are highly productive and are readily established from seed. Timothy, seeded alone or with water-tolerant legumes such as ladino clover (*Trifolium repens* L.) or birdsfoot trefoil (*Lotus corniculatus*), can be used to provide productive ground cover quickly. Reed canary drilled at the same time in widely spaced rows (3 to 4 ft.) will normally spread, over a period of years, to dominate the stand.

In areas of the Western Region where humid conditions and diseases associated with high humidity are not a problem, forage legumes such as alfalfa may provide productive cover.

Influence of Wastewater Analysis

In most localities, municipal wastewater will be required to approach standards for secondary treatment before it is applied on land. Standards for wastewaters from wood products or food processing will be less strict, although primary treatment may be necessary to remove grease or coarse solids which might clog distribution lines or sprinklers.

Often the concentration of nitrogen left after these treatments will determine the rate of wastewater application. The nature of the vegetative cover will be a critical consideration, since the important processes which can remove nitrogen depend on plant activities and plant products.

The fate of phosphorus is less dependent on vegetative effects. Nevertheless, removal of phosphorus by plants will help to extend the useful life of soil minerals which adsorb or precipitate phosphate. Other nutrients in wastewater are of concern mainly in terms of the balance of nutrients needed for vigorous plant growth. In special cases wastewater loadings may be limited by constituents which are toxic to plants, livestock, or humans.

Nutrient Removal Capabilities

If wastewater is applied on vegetation which is not to be harvested, relatively large acreages may be required to provide adequate renovative capacity. Under continuously moist conditions, accumulating masses of dead and dying vegetation can intercept oxygen needed for normal root function. The excessive demand for oxygen can lead to loss of infiltration capacity. Odors and insect problems also may be aggravated. Grasses and other succulent vegetation should be clipped two or three

TABLE 7.1.--Harvested Removal of Nutrients for Selected Crops and Yield Goals.*

	Crop Yields and Nutrients Harvested, Lb./Acre						
Nutrient	Corn Grain	Corn Silage	Wheat Grain	Soybeans	Alfalfa-Brome	Reed Canary Grass†	Hardwood Forest† (Annual Uptake, Lb./Acre)
Yield	150 bu.	25 T.	60 bu.	35 bu.	5 T.	5.5 T.	
Nitrogen	125	165	72	120	220	408	84
Phosphorus	22	30	13	12	30	56	8
Potassium	28	150	14	36	166	247	26
Calcium	3	45	2	5	90	44	22
Magnesium	10	30	4	6	37	40	5

*Ellis, B. G. et al. (10)
†Sopper, W. E. (26)

times a season to stimulate new growth and avoid excessive accumulations of vegetative debris.

Nutrients which are not removed from the site by harvest of vegetation or plant products will tend to accumulate in the system. Some nitrogen will be lost through denitrification, perhaps 15 to 50% if inputs do not greatly exceed the nitrogen required for optimum plant growth. Nitrogen and phosphorus which are retained in a standing crop, detritus, and residual humus must be reckoned with as potential sources of soluble nitrate and phosphate at some time in the future.

The effective life of a system can be extended by removing some of the applied nitrogen and phosphorus in harvested crops. Frequently the first consideration will be to optimize harvest of nitrogen (Table 7.1).

In general, agricultural crops produce more harvestable dry matter with higher nutrient content than tree species grown for timber. Large harvest removals can be achieved with perennial legumes and grasses if they are cut frequently at early growth stages when their nutrient content is high. It should be recognized that legumes can fix all of the nitrogen they need from the air, but they are active scavengers for nitrate if it is present, as well as for phosphate.

The potential for harvesting nutrients with annual crops is generally less than with perennials since annuals utilize only part of the available growing season for growth and active uptake.

Design estimates of harvest removal should be based on yield goals which local experience indicates can be achieved with good management on similar soils. Estimates of nitrogen removal can be extended to allow for effects of roots and surface trash left in the field after harvest. Unharvested residues retard the release of soluble nitrogen during periods when no actively growing crop is present. They also supply energy to support denitrification.

For design purposes, the overall capacity of a crop to remove nitrogen can be estimated at 1-1/2 times the expected removal by harvest. If vegetation or plant products are not harvested, some arbitrarily lower figure will need to be used. Actual removals will vary with many factors of site and management and can only be determined by monitoring in the operational system.

Potential Toxicities

Normally, micronutrient imbalances or metal toxicities will not be a problem with wastewater. In fact, low concentrations of boron, iron, manganese, or zinc may be beneficial to plants on some soils. Increased uptake of cobalt, copper, molybdenum, or zinc into forage may benefit livestock.

Boron toxicity can occur in some situations since this element tends to remain in solution through sedimentation, filtration, and biological treatment. If the wastewater contains more than 0.5 ppm of boron, local agricultural authorities should be consulted regarding tolerant crops which might be grown. If the concentration exceeds 1.0 ppm, it may be necessary to identify and regulate sources of boron in the waste collection system.

Unusual concentrations of organic toxicants (pesticides, industrial chemicals) also will need to be regulated at their source.

Certain hazards are associated with ensiling or with indistriminate feeding of forages maintained at excessively high levels of nitrogen nutrition. Abnormally high concentrations of nitrate can build up in corn, sorghum, and succulent annual grasses if growth is slowed suddenly by drouth, cold, or extended periods of cool, cloudy weather. Nitrate poisoning can result if such roughages are used as the principal ration for livestock. In the silo, nitrate can be reduced to nitrous oxide, a poisonous gas which can pose a serious hazard to personnel for several weeks after silo filling.

Grass tetany (magnesium deficiency) and fat necrosis (intestinal tumors) may be encountered where cattle are pastured on grass receiving high rates of nitrogen. Grass tetany is associated with high inputs of potassium relative to magnesium. Fat necrosis has been found only on heavily manured fescue pastures.

Excessive nitrogen can cause lodging of cereal grains and reduce the processing quality of crops such as sugar beets and potatoes. No toxicities are involved, but such effects must be considered if these crops are to be grown and marketed successfully.

Susceptibility to Disease or Insect Pests

A number of plant diseases and insects which attack plants are favored by moist soils or by atmospheric humidity associated with frequent irrigation. The geographic range and host plant specificity of these pests vary greatly. Frequently resistance to a given pest can be enhanced by selective breeding. State and federal experiment stations and other local authorities should be consulted to determine what pest problems might be anticipated and to identify plant species and varieties which are usefully resistant.

Climate, Soils, Topography

Native plant species or crops whose culture is well established in the general area of the land application site are the most likely choices for vegetative cover since their adaptation to local climate and soils is known. With adequate water and nutrients on well-drained soils, any crop can be grown which is climatically adapted. The availability of water will permit economically valuable species to be grown on

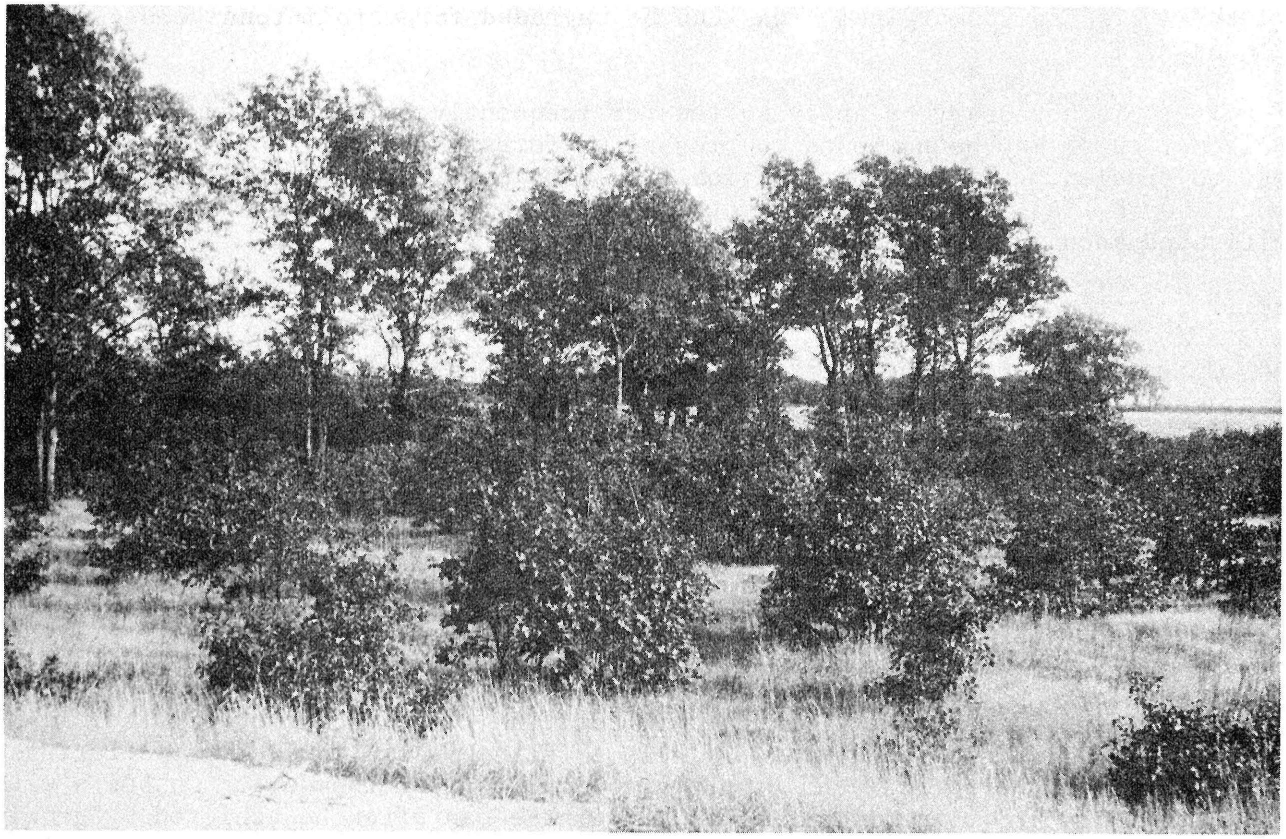

FIG. 7.1.--Scrub oak and sparse native grasses on drouthy, cutover land in northern Michigan, replaced (see Fig. 7.2) by corn irrigated with municipal wastewater. Photo by R. L. Cook.

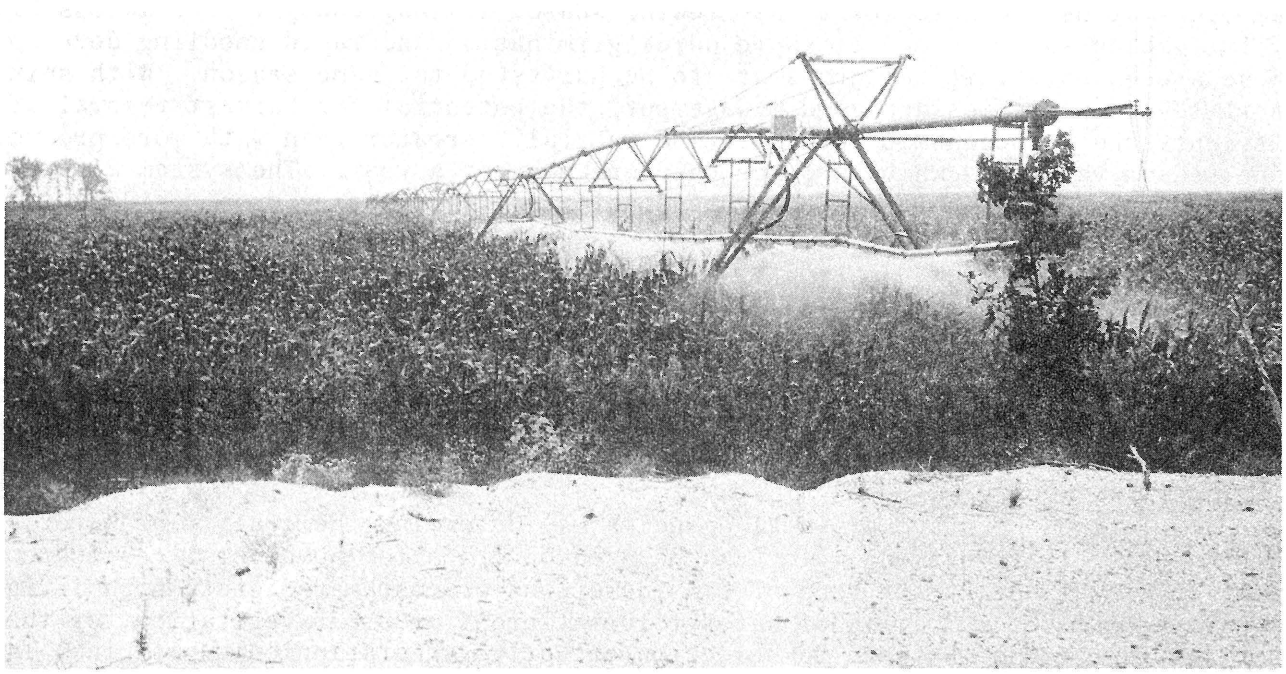

FIG. 7.2.--Corn is a good candidate for irrigation with wastewater. Adapted hybrids with tolerance to important disease and insect pests are available for most areas in the North Central Region. Photo by R. L. Cook.

drouthy soils, so submarginal areas can be upgraded for more intensive uses (Figs. 7.1 and 7.2).

If it is necessary to apply wastewater frequently on slowly permeable soils, the choice of cover may be narrowed to grasses or forest species. On rolling land subject to erosion, year-round protection should be provided through use of perennial species or by fall-planted winter covers and trash mulch systems of management where cultivated annual crops are grown.

Cropping Patterns

Operational efficiencies can be realized through specializing in the production of a single crop for which there is a ready local market, or two or three crops which require similar field equipment and handling facilities. Corn and sorghums are candidates for single cropping because available hybrids cover a wide range of climatic adaptation and tolerance to disease and insect pests.

Monoculture promotes the build-up of specific diseases and insects. Many crops cannot be grown in successive years in the same field for this reason. Rotation of crops interrupts the normal life cycles of host-specific pests and helps to keep their numbers low.

Rotation of crops offers benefits in addition to pest control. Rotations involving cultivated and sod crops will help to maintain or improve soil structure and the infiltration, aeration, and adsorptive capacities of the soil. On soils with tight subsoils, improvements in internal drainage can often be achieved by growing a deep-rooted legume like alfalfa or sweet clover from time to time. Irrigation may need to be discontinued for a season to permit such crops to develop their characteristically deep root systems.

Double cropping--soybeans or silage corn after winter wheat or barley, for example--may be feasible where the growing season is long enough. The accessibility of irrigation water helps to assure quick germination and rapid seedling development. These are essential if two crops are to be harvested the same season. With suitable short-season varieties and good management, the potential for harvest removal of nutrients and for economic return is substantially greater than with more productive long-season varieties which produce only one harvest a year. The system also provides year-round soil protection by vegetation and decomposing crop residues.

Other Considerations

Numerous other factors must be considered in selecting vegetative covers for land application systems. Since large acreages may be involved, the established agriculture of the area and available skills, equipment, storage, handling, transport, and processing facilities are of prime importance, as well as the market potential for crops which might be grown.

Regulations of state or local agencies may determine the quality of water or the schedule of irrigations which can be used on crops for human or livestock consumption. Availability of land or considerations of cost may dictate high irrigation rates and the selection of water-tolerant crops or other vegetation, or these same considerations may lead to selection of native vegetation on submarginal land where wastewater can be applied at low rates or at sporadic intervals.

Management of Wastewater Application Sites

Under provisions of the 1972 amendments to the Federal Water Pollution Control Act, areas used for land application of wastes will be regulated as "non-point" sources of pollution. For this reason, they must be managed as an integral part of the total waste renovation system. The primary objective must be to produce renovated water meeting federal and state standards for surface discharge, groundwater recharge, or special intermediate uses. An important but secondary objective is to realize economic or other benefits which can be credited against the cost of treatment.

Timing and Rate of Wastewater Application

Water suitable for groundwater recharge or for surface discharge of underdrainage can be obtained by low-rate irrigation. Application rates should not exceed the soil's capacity to accept water without runoff or without ponding for more than an hour or two. Instantaneous rates on intertilled crops should not exceed 0.5 inch per hour on loamy sands or 0.1 inch per hour on clay loams. Somewhat higher intensities may be feasible on grass or forest vegetation. To avoid excessively rapid transit through the soil, the total application should not exceed 1.5 to 2 inches in a 24-hour period--even on soils which will accept more water.

Weekly loadings and irrigation schedules should allow sufficient residence time for waste constituents to interact with soil systems and plant roots. On permeable soils, up to 4 inches of water per week (including rainfall) may be feasible during summer and early fall when evapotranspiration is high. At other times, treatment-effective loadings will be much less because of precipitation surpluses and reduced biological activity. Wastewater containing high concentrations of nitrate should not be applied on cold soils (below 50° F.) when vegetation is dormant and denitri fication occurs slowly or not at all.

Winter irrigation of cultivated cropland should not be considered in the northern tier of states in the North Central and Western Regions. On grass or forest vegetation, winter irrigation with low nitrate water at reduced rates may be feasible, except during very cold weather or when soils are frozen.

Irrigation schedules should allow for resting periods between applications for drainage and aeration of the root zone. This is commonly achieved by irrigating every 2 to 10 days. Longer intervals are required during cold weather than at normal growing season temperatures. Oxidizable organics (BOD) applied with wastewater can build up in surface soil to the extent that infiltration and aeration are interfered with and anaerobic conditions develop which are conducive to odors. This is frequently the factor which determines how often processing wastes high in BOD can be applied in low-rate irrigation systems. In cold weather it also can be a factor with wastewater pretreated to reduce BOD.

Rapid infiltration is not essential for treatment of wastewater by overland flow. Some deep percolation can occur, depending on slope and soil type. However, the main flow of water is downslope--over the surface or by seepage through upper soil layers. Suspended solids are filtered out on vegetation, litter, and soil. Thus, they are distributed over a very large surface area exposed to the air. BOD is dissipated rapidly, even at near-freezing temperatures. Effective residence times can be achieved on uniform slopes of 0 to 6% with downslope exposures of 150 to 200 feet. Daily applications can be made, except during rainy weather. During cold weather, applications may need to be less frequent or discontinued if soil and litter are frozen.

Nitrogen can be removed effectively by overland flow. At temperatures below 50° F., however, nitrate in the wastewater may pass through the system unaltered since very little will be taken up by the vegetation or removed by denitrification. Much of the ammonium and organic nitrogen filtered out from winter applications may be released rapidly as nitrate when biological activity resumes in the spring. Phosphorus is removed less effectively than nitrogen. Runoff from overland flow may not meet standards for discharge and may need to be diverted for low-rate irrigation on other land areas or for permitted uses in industry.

In both overland flow and low-rate irrigation systems, water applications must be discontinued well in advance of field operations so soils can drain and stabilize to carry tillage or harvest equipment without serious impairment of soil structure. Applications should not be made on bare soil except as needed to promote germination and rapid development of a newly planted crop.

Tillage and Residue Management

Tillage operations which expose bare soil should be kept to a minimum. Conventional plowing (8 to 10 inches) and preparation of a seedbed free of weeds and trash are necessary for most vegetables and root crops. Many field crops, however, can be planted directly in sod or trash from a previous crop or after partial incorporation of residues by shallow discing. On some soils, it may be necessary at some time to plow very deep (2 ft. or more) to mix impermeable subsoil strata with more permeable surface materials. More often, impermeable pans formed by vehicular traffic or by natural processes can be broken up by subsoiling equipment which leaves the surface protected by vegetation or stubble and trash.

Minimum tillage and no-till methods conserve fuel, reduce labor costs, and minimize compaction of soils by heavy equipment. Crop residues left on the surface or partially incorporated to a depth of 3 or 4 inches provide protection against runoff and erosion during intervals between crops. The decomposition of residues on or near the soil surface helps to maintain a friable, open condition conducive to good aeration and rapid infiltration of water.

Local soil conservation district personnel should be consulted regarding tillage practices appropriate for specific crops, soils, and terrain.

Vegetative covers should be managed to promote both a high rate of nutrient harvest and frequent return of unharvested residues. Return of residues is particularly important where wastewaters have been treated to reduce BOD. The residues serve to restore an effective balance of energy and structural carbon relative to nutrients and toxicants. The cycling of nitrogen and phosphorus through decay organisms and their products helps to regulate the release of soluble nitrate and phosphate. Actively decomposing organic matter also helps to reduce the concentration of other soluble pollutants and can hasten the conversion of toxic organics, like pesticides, to less toxic products. Carbonaceous solid wastes or wastewaters high in BOD, from canneries or wood processing industries, can be used to augment production of organic matter by on-site vegetation. Minimum tillage or no-till methods will reduce decomposition rates and help to maintain or increase the level of cycling organic matter in the soil.

Another approach for restoring the carbon balance in pretreated wastewaters is to manage lagoons and holding ponds so as to promote growth of aquatic plants. These can be harvested for feed or for application on land.

Nutrient Imbalances, Toxicants, and pH Control

Wastewater applications in a given situation may be limited by one or a combination of several loading parameters: water, suspended solids, BOD, phosphorus, soluble salts, sodium, or in special cases by certain micronutrients, metals, or toxic trace organics. In any case, nitrogen loadings should not exceed 1-1/2 times the anticipated removal of nitrogen by harvest except as justified by actual monitoring experience on the site.

At this level of nitrogen input, many wastewaters will supply other essential nutrients in quantities adequate for optimum production of crops. Nutrient imbalances may occur, however. These must be corrected since vigorous growth and high yields are essential to assure efficient removal of eutrophying nutrients by harvest and maximum benefits from living vegetation and decomposing residues.

Nutrient imbalances can be identified by visual symptoms and quick tissue tests in the field. Field diagnoses can be confirmed by detailed analysis of plant tissue sampled at a critical stage of growth. Often, developing deficiencies or toxicities can be detected, before serious imbalances occur, by testing soils systematically every year or two for available nutrients and pH.

The balance among major and secondary nutrients is of primary concern. Analytical determinations should be made for phosphorus, potassium, calcium, and magnesium, using methods of known diagnostic value for soil or for tissue, as the case may be. Total nitrogen (Kjeldahl N) can be useful, but the level of nitrate (NO_3^-) in tissue or soil is a more sensitive indicator of the nutritional status of plants with respect to nitrogen. Nitrate also should be determined in forages or leafy vegetables if there is reason to suspect concentrations which might be toxic to livestock or humans.

Imbalances involving micronutrients and other metals will be determined mainly by soil pH rather than by their concentrations in the wastewater. Toxicities are most likely under acid conditions and may develop simply because of the increased availability of native soil sources. Deficiencies of essential micronutrients are more likely under alkaline conditions. Molybdenum and selenium are exceptions, and forage contents toxic to animals have been associated with soils above pH 7.0.

Problems of deficiency or toxicity will be minimized if surface soils are maintained at pH 6.5 to 7.0. This can be done by adding lime to acid soils or sources of acidity (alum, sulfur, iron sulfate) to alkaline soils, as indicated by soil tests made every 2 or 3 years. If the wastewater is very acid (pH 4.8 or lower) or very alkaline (pH 8.3 or higher), these extremes will need to be neutralized before the water is applied on living vegetation.

Supplemental nutrients to correct deficiencies can be applied through the irrigation system or by suitable attachments to tillage or planting equipment. Supplemental fertilization should be gauged to actual needs and regulated as indicated by visual symptoms or by changes in soil or tissue tests.

Abnormal tissue analyses and visual symptoms can be caused by conditions, such as high salt concentration or poor soil aeration, which impair root functions. Salt concentrations in certain processing wastewaters may be high enough to cause direct injury to plants unless salt tolerant species are grown. More often, injurious salt concentrations build up during the growing season in soils which do not transmit water fast enough to assure leaching. Wastewaters with unusual salt content (high electrical conductance) should not be used for low-rate irrigation on slowly permeable soils unless means can be found to improve internal drainage.

Loss of soil permeability may result from effects of waste constituents such as clay or sodium. If sodium is responsible, it may be necessary to increase the calcium content of the wastewater or to amend the soil with sources of calcium (gypsum, slag, lime). Deep tillage or the installation of additional tile for underdrainage may be needed to assure rapid movement of salts and sodium through the soil. Improvements in internal drainage also will improve soil aeration.

Pest Control

Problems with weeds, insects, and plant diseases are aggravated under conditions of frequent irrigation, particularly when a single crop is grown year after year or when no-till practices are used. Most pests can be controlled by selecting resistant or tolerant varieties and by using pesticides in combination with appropriate cultural practices. State and local experts should be consulted in developing an overall pest control program for a given situation.

Harvesting

Most crops require a period of dry weather before harvest to mature and reach a moisture content compatible with harvesting equipment. Additional drying by artificial means may be necessary for safe storage or to meet market standards. Soil moisture at harvest time should be low enough to minimize compaction by harvesting equipment. For these reasons, irrigations must be discontinued well in advance of harvest.

To minimize disruption of irrigation schedules, harvesting and any tillage or planting operations which follow must be carried out expeditiously. Adequate power, labor, and equipment must be provided for this, allowing for inevitable delays due to weather (Fig. 7.3). Poorly drained areas in a field can lead to expensive delays (Fig. 7.4). Operations in such areas should be avoided until adequate improvements in drainage can be effected.

Personnel

A wide range of managerial and technical skills may be needed to coordinate land application with the collection, pretreatment, and storage of wastewater in a total waste treatment system. A central core of professional expertise in sanitation and irrigation engineering as well as the agronomic sciences is essential for a well-managed land application site. Analytical capabilities for the monitoring required by state agencies must be provided within the organization or by contract with independent laboratories. These, plus necessary administrative and clerical personnel, technicians, and labor, may suffice if wastewater is applied on submarginal land with minimum management.

If there is concern for upgrading land use or for realizing economic return from application of wastewater, other competencies will be required. Specific skills will depend upon the proposed use of the land--whether for wildlife, recreation, forestry, or agriculture. Managers for such areas should have professional training or unique interests and experience appropriate for the type of management required. Technical and mechanical skills will vary with the nature of the resource. Semiskilled labor may perform many tasks, but well-trained personnel are needed to train and supervise them.

FIG. 7.3.--Timeliness in field operations requires heavy equipment and personnel skilled in its use and maintenance. Soils must be allowed to drain and stabilize before such operations. Photo by R. L. Cook.

FIG. 7.4.--Poorly drained spots in a field will be unproductive and can cause expensive delays. Additional tile are needed here. Deep tillage may be needed to repair damage to soil structure. Photo by R. L. Cook.

In some situations it may be feasible to distribute wastewater to independent operators. Such arrangements should be contractual. Legal counsel should be sought in drawing up agreements which are mutually advantageous and yet retain rights of access for monitoring purposes and provide for courses of action in the event that water quality standards for discharge or groundwater recharge are not met. Personnel and organization must be provided to administer such contracts.

Key individuals should have responsibilities for liaison with regulatory agencies and for informational and educational exchange within the organization and with the general public.

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Section 8

SELECTION OF THE SYSTEM for Wastewater Application on Agricultural Land

Ernest H. Kidder

Three methods of wastewater application to land are considered. They are sprinkler irrigation, surface irrigation, and overland flow. Infiltration-percolation systems are not discussed.

In the Western states, including those in the western part of the North Central Region, both surface and sprinkler irrigation methods may be used. In the Eastern states, the amount of land leveling and the resulting damage to the soil profile would in most instances eliminate surface irrigation. The injection of wastewater into the soil by knifing does not appear to be practical because of the disturbance to the crop and to the soil which would result from weekly applications, and because of the high cost of operating the application equipment. A renovation and utilization concept of wastewater application is emphasized.

Water Management Strategies

Certifiable waste treatment plans may include cycles of re-use for purposes which do not require water of the quality specified for terminal discharge. Uses which generate revenue will contribute directly to the cost effectiveness of a system. Such uses are to be found in industry, agriculture, forestry, and aquaculture.

There are beneficial uses of partially renovated water which may produce little or no revenue but which can influence the quality of life and, indirectly, the economic and social goals of communities and regions. These include irrigation of public and private landscaping, greenbelts, and wildlife habitats, and containment and control of surface flows for recreational and aesthetic purposes. Land application and surface containment of wastewaters can lead to increased recharge and storage in local groundwaters, with increased efficiencies in water use. Increased retention of water in local reservoirs (holding basins, cyclic re-use systems, soils, groundwaters) can contribute significantly to moderation of seasonal and long-term fluctuations in stream flows and lake levels.

An essential objective in total design must be to provide for containment, monitoring, and control of wastewater flows until water of the desired discharge quality is achieved. Seasonal and cyclic fluctuations in wastewater and storm water flows originating within the system, and in natural flows entering from outside, must be anticipated in the initial design. Probable increases in volume or changes in quality of flows requiring treatment must be allowed for initially, or anticipated in contingency plans for expansion or for adoption of new treatment technologies, as needed, over the projected life of the system.

Design and management options for application of wastewaters will vary with the hydraulic capabilities of available soils and terrain and their relation to natural and engineered hydrologic systems (Table 8.1).

The renovative capabilities of soils and vegetation are utilized most effectively with low rate irrigation systems (Fig. 8.1). With appropriate management, drainage water suitable for surface discharge or percolate suitable for groundwater recharge can be obtained. Economic benefits from increased efficiencies in produc-

TABLE 8.1--Comparative Characteristics of Low-rate Irrigation, Overland Flow, and Infiltration-Percolation Systems.*

	Design Approach		
Factor	Low-rate Irrigation	Overland Flow	Infiltration-Percolation
Liquid loading rate	0.5 to 4 in./wk.†	2 to 5.5 in./wk.	4 to 120 in./wk.
Annual application	2-8 ft./yr.	8 to 24 ft./yr.	18 to 500 ft./yr.
Land needed per 1 mgd	140 to 560 acres plus buffer zones	46 to 140 acres plus buffer zones	2 to 62 acres plus buffer zones
Soils	Moderately permeable loamy sands to clay loams	Slowly permeable silt loams to clays	Rapidly permeable sandy loams to sands
Slopes	Cultivated crops: 0-6%. Forages and forest species: 0-15%	2-6%	Less than 2%
Removal of suspended solids and BOD	90 to 99%	90 to 99%	90 to 99%
Removal of nitrogen	80 to 100% (may exceed 100%)	70 to 90%	0 to 80%
Removal of phosphorus	95% to 100% (may exceed 100%)	50 to 60%	70 to 95%
Fate of wastewater	Evapotranspiration and deep percolation for groundwater recharge, discharge into surface waters, or recovery and re-use. Runoff controlled	Runoff maximized for recovery and re-use. Relatively little evapotranspiration or deep percolation.	Deep percolation maximized for groundwater recharge, recovery and re-use. Runoff not allowed. Negligible evapotranspiration.

*Adapted from R. E. Thomas and C. C. Harlin, Jr. (28) and C. E. Pound and R. W. Crites (23). EPA-660/2-73/006a.

†Irrigation at 4 in./wk. would be seasonal. An 8 ft./yr. application would average 2-1/2 in./wk. over a 40-week irrigation period.

IRRIGATION SYSTEM

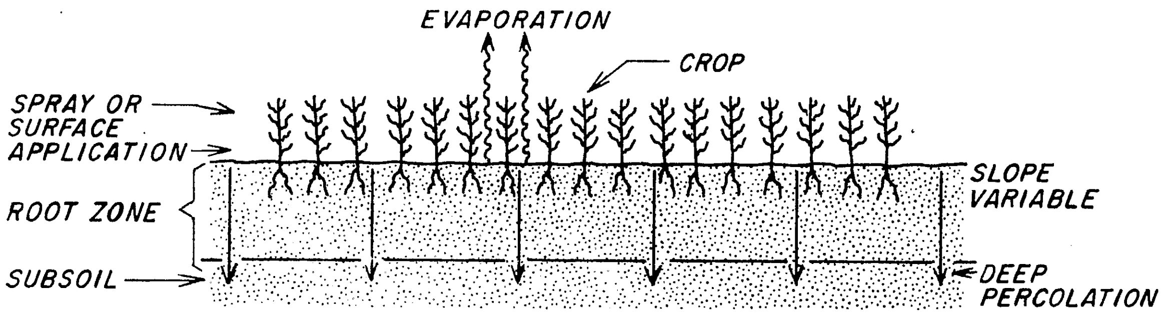


FIG. 8.1.--Diagrammatic representation of the low-rate irrigation system for wastewater renovation.

tion or increased yields of crops will compensate for increased costs for transmission and distribution of partially treated wastewater and the need to extend managerial control over relatively large acreages. In most cases, municipal effluents to be applied through low-rate irrigation systems will be required to meet standards for secondary treatment with regard to BOD, suspended solids, fecal coliforms, and pH.

The permeability of fine-textured loams and clays is too low to accept and transmit significant quantities of water in excess of normal precipitation in the humid areas (see Section 2). On such soils, substantially renovated water for re-use can be obtained by controlled overland flow. Other descriptive terms for this approach are "hillside irrigation" and "grass filtration." The filtering action of vegetation and associated organisms at or near the soil surface can remove suspended solids and organics as effectively as conventional primary plus secondary treatment.

Sprinkler Irrigation

Sprinkler irrigation involves spraying water out through the air. The water normally infiltrates the soil at the point where it falls. During recent years, a number of mechanical systems have been developed for use on large areas. These systems generally work quite well and a minimum of labor input is needed for their operation (Fig. 8.2).

SPRINKLER IRRIGATION

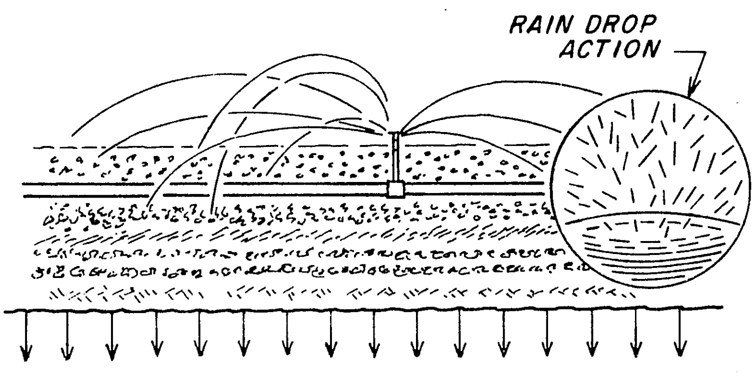


FIG. 8.2.--Diagrammatic representation of a sprinkler irrigation system for applying wastewater to land.

TABLE 8.2.--Range of Infiltration Rates for Various Soil Textures.

Soil	Infiltration Rates
	in./hr.
Coarse sand	0.50 to 1.00
Fine sand	0.30 to 0.80
Sandy loam	0.25 to 0.50
Silt loam	0.25 to 0.40
Clay loam	0.20 to 0.30
Clay	0.10 to 0.25

Sprinkler irrigation is used extensively for the application of wastewater. Rotary sprinklers, which range in capacity from 0.5 to 1,200 gallons per minute, make possible a wide range of application rates. The soil texture, structure, and vegetative cover largely dictate the maximum water intake rate. Approximate infiltration rates based on soil texture are given in Table 8.2.

It must be pointed out that the infiltration and percolation rates are a function of time, cropping practice, quality of water, permeability of deeper soil layers, and antecedent moisture in addition to the soil texture. It is strongly recommended that infiltration and percolation tests be made at intervals along a radius line on the specific soil (for methodology, see Appendix A). Observations during these tests will provide the initial estimate of the application rate.

Because the water from the rotating sprinkler is projected through the air, there is concern about the drift of tiny droplets (aerosols). Hence, isolation from public roads and private property must be prescribed when sprinkling wastewater. Some testing is being carried out with sprayer type nozzles and other applicator devices at crop level in an attempt to reduce droplet drift by directing the spray downward, decreasing the opportunity for droplets to become airborne.

The type of equipment used to apply the wastewater will vary depending on the land area involved, available labor, economic and climatic factors.

Solid set type systems have been used, consisting of permanent buried or quick coupling portable pipe laterals using properly spaced rotary sprinklers. Several mechanized systems also are available. The side roll lateral in which the pipe becomes the axle to turn the supporting wheels is suited to low-growing crops. It requires about an hour's labor every few hours to roll the lateral to a new setting.

The central pivot system, as the name implies, uses a lateral line supported by towers to rotate about a pivot point. Great flexibility is available both in application rates and rotation speeds. The system is powered by water hydraulics, oil hydraulics, electric motors, air pressure, or mechanical cable. A rotation period of one revolution in 8 hours makes three rotations in 24 hours possible.

A third type of system is a giant or boom sprinkler pulled through the field by a winch. This traveling unit is supplied by a drag, high pressure, flexible hose. Both its speed of travel and application rate can be adjusted. It takes about an hour's time to reposition the applicator unit, drag hose, etc., after each trip through a field. This unit is commonly used in 40-acre fields and irrigates about

10 acres with each trip through the field. However, giant sprinklers project water high into the air and result in aerosol drift for a greater distance than smaller sprinklers.

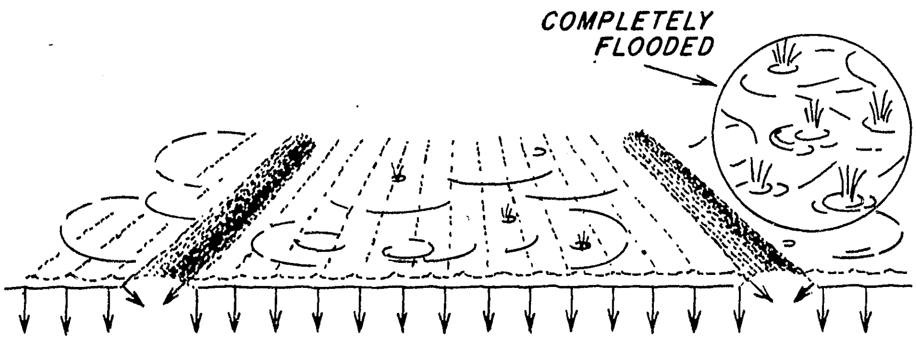
Surface Irrigation

Surface irrigation includes all systems which allow water to flow over the soil surface and continually infiltrate as it flows. The land must be rather flat with no excessive slopes for this system to be feasible (Fig. 8.3).

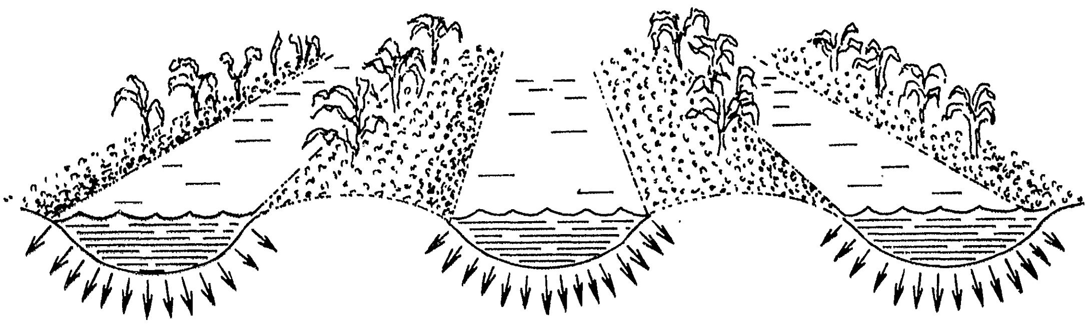
Generally, some land shaping is necessary to level the surface to a sloping plane for efficient irrigation. The depth of top soil present should be considered in planning for land leveling. Surface irrigation has not been extensively studied for use in renovation of wastewaters, but is likely to be used in cases where aerosol effects limit sprinkler irrigation. The various surface irrigation systems are described and evaluated regarding their potential use for land application.

In one system, a ditch or a pipe distribute the water to the high end of the field where it is discharged onto the surface. If a ditch system is used, various structures are required to assure that water in the supply ditch is at the proper

SURFACE IRRIGATION



FLOODING



RIDGE AND FURROW

FIG. 8.3.--Diagrammatic representation of two surface irrigation methods for applying wastewater to land.

elevation. Pipe systems may be either buried pipes with risers which bring the water to the surface or may be gated pipes placed on the surface of the soil. Where surface irrigation is used, a ditch system is required for collecting and handling excess water which runs off the lower end of the field. This runoff could be applied to a lower field, pumped back to its original supply ditch and applied again to the same or other fields, or returned to storage.

In another system, the entire surface of the soil may be inundated or small channels may be formed to carry the flow over only a part of the surface. The partial flooding systems are called furrow irrigation if a row crop is involved. Smaller channels similar to furrows used for a cover crop are generally spaced closer and are called corrugations. Ridge and furrow irrigation involves the use of large channels with crops planted on ridges between furrows. These large furrows may be flat, forming long narrow basins which are filled and allowed to set while water infiltrates from them.

Any of the partial flooding systems should be applicable to wastewater irrigation. When water contains some suspended solids, the surface of the furrows may tend to seal after they have been wet for several hours, but a period of rest during which the soil surface is allowed to dry should restore the infiltration rate. Bendixen, *et al.* (3) report satisfactory operation of a ridge and furrow system in which effluent from a two-stage trickling filter was applied to a silt loam soil. In some cases occasional tillage of the furrow may be necessary to fully restore the infiltration rate.

Land prepared for furrow irrigation also provides good surface drainage for handling runoff from heavy precipitation. Furrow systems would be advantageous for wastewater application because water does not contact the plant foliage and hence wastewater residues are not deposited on the plant.

For surface irrigation where the entire surface is flooded, an earth structure is required to guide the flow. For conventional border irrigation, small levees guide the flow down the slope. Contour borders with dikes along the contours, or contour ditches which distribute the flow across the slope and allow water to flow from one ditch to the next one down the slope, also are used.

Border irrigation appears to be the surface irrigation system with the most potential for use in wastewater renovation. It has been studied rather extensively and rational design criteria have been developed. Border widths usually range from 30 to 60 feet and slopes down the border are between 0.1 and 1%. Length of runs ranges from 300 to 1320 feet. Slope across the border must be nearly zero.

The border irrigation system can be adapted to most soil types and can be designed to work well even on sandy soils by using higher application rates. This type of irrigation is generally used for grain and forage crops. Furrows may be formed in border strips to irrigate row crops.

The development of automatic control systems for surface irrigation has been slow. They are not totally perfected, but several ideas show promise and have been successful in limited field use. Automation of a surface irrigation system requires control of gates or checks in the supply system to provide for delivery of water to the proper field location, and sequencing the opening and closing of turnouts which deliver the water from the supply to the field. The devices which have been developed to control the flow of water in supply ditches are checks and drop gates which may be timer-controlled or operated by remotely controlled hydraulic cylinders. By

OVERLAND FLOW IRRIGATION

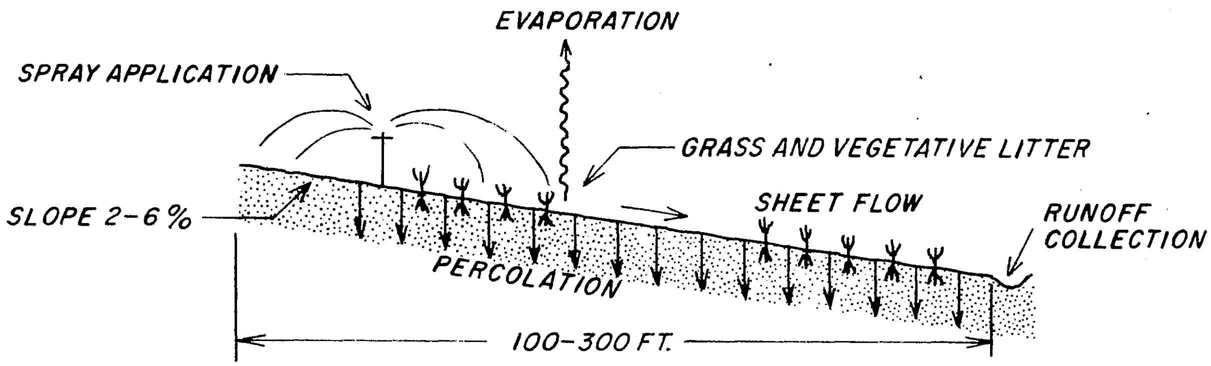


FIG. 8.4.--Diagrammatic representation of the overland flow method of applying wastewater to land.

setting time clocks prior to the beginning of an irrigation, water can be advanced from point to point along a ditch by removing checks at set time intervals.

Overland Flow Irrigation

Overland flow (Table 8.1, Fig. 8.4) has been used successfully for renovating food processing wastewaters and is presently being studied for renovating municipal wastewaters as well [Carlson *et al.* (6), Hoeppel *et al.* (17)] If feasibility can be demonstrated, overland flow might be used to renovate wastewaters from communities in areas with soils of low permeability. Land-formed smooth slopes and a length of run compatible with the soil texture are necessary to assure even distribution, effective detention times, and containment and recovery of runoff. In effect, overland flow irrigation is a form of surface irrigation known as border check. The emphasis is on "cleaning up" the large volume of water which flows down the slope to be collected at the base of the slope for other use (Table 8.1).

None of the points mentioned previously will allow for the complete design of a wastewater application system. The final choice and design of a wastewater application method involves the input of a competent engineer, soil scientist, crop scientist, and economist, as well as consideration of the regulations of local, state, and federal agencies.

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Section 9

PUBLIC HEALTH AND NUISANCE CONSIDERATIONS for Sludge and Wastewater Application to Agricultural Land

Thomas P. Wasbotten

Plans for any proposed sludge and/or wastewater application project should be reviewed with the local unit of government where the project is located for compliance with local ordinances. Local, county, or district health departments should also be contacted to obtain pertinent information on health regulations. The state water pollution control agency should be contacted and they should be able to provide direction on any requirements of other state agencies. Assistance can also be provided by the U.S. Environmental Protection Agency, the U.S. Department of Agriculture, Cooperative Extension Service, and the Food and Drug Administration.

In evaluating overall environmental impacts of any land application of wastewater effluent or sludge system, consideration must necessarily be given to potential public health hazards and offensive odor nuisances. Effects that must be considered include groundwater quality, aerosols, contact with the wastewater or sludge by the public and employees operating the facilities, insects and rodents, isolation from the public, stormwater runoff from the site, and contamination of the crops.

Odor Control

Since state and federal government regulatory agencies require that sufficient level of preliminary treatment be provided for wastewater systems (usually the equivalent of secondary treatment), odor nuisance conditions should not be experienced in the actual application of wastewater to the land. Experience with industrial wastewater where offensive odor nuisance conditions have existed generally shows the cause to be the result of inadequate treatment prior to land application, often compounded by excessive ponding on the irrigation site. A more likely location for the correction of offensive odors is at the source of the putrescible wastewater constituents.

Sludge applications to the land pose a much more serious potential for offensive odor nuisances if not properly managed. Odor problems can begin at the point of initial sludge handling and the odor potential can extend for a significant period of time after the actual application of sludges to the land. Since sludges produced from wastewater treatment facilities vary greatly in liquid or solid consistency, chemical composition including chemicals which may be added for sludge conditioning, and type and degree of preliminary treatment (very important with respect to odor generation), a case-by-case evaluation is usually necessary.

Plans for land application should include provisions for soil incorporation of sludge prior to rewetting of the sludge by the next significant rainstorm. Liquid sludge application methods employing subsurface injection and liquid manure spreading followed by plowing and discing have been cited in the literature as being successful. Other treatment and odor control methods for sludge have included heat treatment followed by sludge dewatering, composting, chemical treatment with high concentrations of lime and chlorine, and pressure filtration of sludge cake. The application of well-digested drying bed sludge to land has been successful for many years and is still probably the most economical and normally odor-free method for smaller facilities.

The often employed method of applying liquid digested sludge to farmland has not always been an odor-free method, but has been tolerated at isolated locations because of the lack of frequency, duration, and intensity of the odors generated from the application area in small installations. Many of these operations are faced with citizen complaints and litigation as the frequency of application increases due to greater volumes of sludge generated at the wastewater treatment plant and with adjacent land use changes (*i.e.*, a new residential type house in the country; the adjacent farmer stopping his livestock operation and growing crops, thus eliminating the manure handling operation, etc.). However, with proper sludge digester operation, sludge handling techniques, and land management at the application site, these odor problems can be kept to a minimum. Better management procedures should be planned for new sludge application systems rather than just duplicating so-called "successful systems" in a neighboring community.

Pathogens

The most serious question raised in land application systems for wastewaters and sludges from a public health aspect is the potential for the transmission of pathogens, including both bacteria and viruses. Transmission can potentially occur via the groundwater, via man coming into physical contact with either the wastewater or sludge, via the food chain or handling of the crop grown on the land, and via aerosols. In general, control methods have consisted of multiple barrier restrictions imposed by health regulatory agencies, including such techniques as immunization of employees of wastewater treatment systems, requirements for the disinfection of wastewater, the degree of digestion of sludges required before application, and isolation of wastewater and sludge handling facilities from the public.

Although the soil is generally agreed to be an excellent filter and inactivator of bacteria and viruses, the literature cites a number of cases where both viruses and bacteria have traveled significant distances through the soil mantle. Of comparable concern, from a public health standpoint, is the protection of the groundwater aquifer from contamination by other wastewater or sludge constituents including nitrate nitrogen. Many states require that the minimum U.S. Public Health Service drinking water standards not be exceeded for any existing wells in the vicinity of the project. Others require no measurable degradation to water quality from existing wells or from future wells as a result of the project.

Aerosols are microscopic droplets which could conceivably be inhaled into the throat and lungs. Aerosol travel and pathogen survival are dependent on factors such as wind, temperature, humidity, vegetative screens, distance, etc. Little is actually known about the survival of pathogens in aerosols, but research projects are underway to evaluate this potential hazard. Current methods employed to reduce this potential problem include isolation distances, vegetative screening, effluent and sludge application techniques reducing aerosolation, *i.e.*, low pressure, large droplet spray irrigation equipment, stopping of spraying during high winds, and disinfection prior to application.

Parasites

The ova of intestinal parasitic worms are excreted in the feces of infected individuals and are regularly present in raw sewage. Of particular concern have been ova of *Ascaris lumbricoides*. These ova are generally resistant to adverse environmental conditions and are still present in both treated wastewaters and sewage sludges. Concern with food chain transfer by the sludge-milk-human route has prompted at least one State Health Department (Ohio) to restrict sludge application to dairy pastures. This is an area requiring an immediate, intensive research effort.

Insects and Rodents

The control of insects and rodents on a land application site is more critical than for either other agricultural land or irrigated agricultural land because of the possible transmission of bacteria and viruses from the wastewater or sludges. Wetter conditions and increased vegetative cover also increase the potential for the number of insects and rodents; however, conventional methods of control can normally be utilized to control these pests. Mosquito propagation could be severe on wastewater application sites unless the facility is properly designed and managed to eliminate ponded water and allow for sufficient drying periods between applications of wastewater.

Isolation from the Public

A number of constraints may be placed on wastewater and sludge land application sites by local, state, or federal regulatory agencies that have current authority to isolate the site from the public and from potential odor nuisance and health hazards. Sites utilized exclusively for wastewater or sludge management systems must often be suitably fenced and posted to inform the general public of the use of the site. Isolation distances should be provided proportional to the degree of potential health risk of aerosols from wastewater irrigation sites and risk of odor nuisance from sludge application sites. Minimum distances may be imposed from residences, water supplies, surface waters, roads, parks, playgrounds, etc. Public access should only be on a regulated basis with due consideration given to the additional health hazards associated with wastewater or sludge.

Stormwater Runoff from the Site

Along with the need to protect surface water quality, surface runoff from wastewater and sludge application sites must be managed to protect adjacent landowners. Commonly, berms and dikes are used to eliminate surface runoff from wastewater irrigation sites. Grass filtration wastewater irrigation systems should have collection systems with additional treatment and disinfection to assure the resultant discharge to surface water meets discharge requirements. Surface runoff from sludge application sites can usually be controlled by conventional agricultural soil erosion control methods. With high rates of liquid sludge application, additional precautions may be necessary to control surface runoff to reduce potential health hazards and nuisance problems.

Contamination of the Crops

Almost all states either prohibit or tightly regulate the growth of crops directly consumed by man where sludges or wastewater effluent are applied. Of recent concern are the largely unknown health effects of heavy metals, PCB's, mercury, and other potential toxicants which may enter the food chain. Common practices to reduce this potential involve control or elimination of the discharge of these toxic chemicals at the industrial wastewater source. A prohibition of application of these wastewaters and sludges to the land where agricultural crops or livestock operations would cause a potential food chain problem could be applied by governmental regulatory agencies.

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Section 10

PUBLIC ACCEPTABILITY AND LEGAL CONSIDERATIONS for Sludge and Wastewater Application on Agricultural Land

Terry F. Glover

Renovation of municipal wastewater and sludges on land is not particularly a new concept, but it has undergone a recent revival because of water quality and economic concerns. Such systems of renovation, if properly implemented, can greatly reduce nutrient build-up in water courses and place the nutrients on land where they can be used beneficially. Applying wastewater and sludge to the land is often a more cost-effective waste treatment alternative than conventional renovative and disposal techniques. However, municipal authorities and the public must recognize that certain problems may arise when they consider the land renovation alternative. Among these problems are concerns and procedures for acquiring the needed land for such a system and the general acceptance by the public of the land treatment concept.

Legal and Economic Arrangements

Land Arrangements

Land treatment of municipal wastewater and sludges is an alternative that should be evaluated after considering specific community conditions and goals. Once a decision is made to employ land treatment, a variety of land acquisition options can be used. Each will have different impacts on landholders and the goals of municipal authorities. The variety of the options used reflects varying capacities of communities to impose costs on landowners.

Fee simple acquisition of land (outright purchase) provides better control of the renovation system by municipalities. It enables the municipality to pursue its own goals within state, federal, and local law. However, the municipality is generally required to pay high land costs for the fee interest property rights and, in addition, is required to add another function (agricultural production and management) to its existing service activities. Land purchase is also more disruptive to farmers and local agricultural economics relative to other types of land acquisition arrangements.

In the North Central Region, municipalities will currently have to pay in the range of $650 to $1,800 per acre for agricultural land which is suitable for renovation of wastewater and sewage sludges. To purchase a farm unit and relocate the family under condemnation procedures would currently cost in the range of $18,000 to $26,000 for the farm headquarters buildings, plus approximately $8,000 in relocation costs in addition to the land costs. This assumes the average tract of land to be a 160-acre unit.

Easements or use rights (other than fee interest) on suitable land can be obtained without acquiring full property rights if mutual gains for the municipality and farmer(s) exist. Such use rights could run the gamut of permanent easement to seasonal land use agreements. Use-right arrangements reduce the control of the treatment system by municipalities but lower the land cost and are less disruptive to the local economy.

Acquiring the use of land via use-right arrangements usually meets with better public acceptance than land acquired by fee simple acquisition. Further improvements in acceptability occur if all risks and unknowns of the renovation system are minimized, fertilizer nutrients to farmers are made available economically with no inconveniences, and farmers' costs are reduced as a result of the arrangement.

One example of an inconvenience and unknown is excess water. Excess water is a problem in most of the North Central states. Thus, application of wastewater to land will be met with skepticism by farmers since they require nutrients as inputs to their production activities but do not require greater water use. Excess water imposes drainage costs in addition to the costs of irrigation. Such costs will have to be borne by the municipality before they can negotiate for use rights to apply wastewater to land (7, 16). In contrast, the water may be a distinct asset which will attract use-right arrangements in more arid states of the United States.

Negotiations between municipal authorities and farmers to apply municipal sludges to land will not meet with these problems since the quantity of water applied with sludges is insignificant. However, farmers who apply sludges must be assured that their soils or crops will not be temporarily or permanently damaged by factors such as excess heavy metals or soluble salts.

Payments to the farmers or landowners for any use-right arrangement will certainly be involved if uncertainties with respect to the application of wastewater and sludge to the land exist; *e.g.*, unknown heavy metals, harmful salts, unknown irrigation rates, etc. These payments by the municipality to farmers will probably amount to approximately the existing net agricultural land rents in the area since farmers stand to lose at least that much money if problems arise. For corn-soybean land in the Corn Belt, such rents currently run in the range of $35 to $60 per acre. If drainage is required, current tile and drain structure costs range from $200 to $550 per acre, depending on local soil and topographic conditions. This figure assumes 10% of the total drainage structure is already in place.

Land may also be acquired for use from wastewater or sludge farming cooperatives. In such case, an agreement is made between the municipality and a group of landholders organized into a cooperative for the purpose of receiving and using given amounts of wastewater or sludge generated by the municipality. The application rate and timing of wastewater or sludge applications to the land is largely determined by the members of the cooperative. Some studies in Michigan and Ohio suggest that even under this arrangement, most additional irrigation and drainage costs would have to be borne by the municipality in the form of a payment to the cooperative. Negotiations often break down if farmers' inputs are altered greatly because of additional capital for modified drainage or irrigation systems.

Investment costs of sludge application equipment may be spread among farmers in a cooperative arrangement. Operating costs may be included in the cost of sludge delivered to the individual farm unit. Data for sludge analysis (nutrients and other elements) would have to be provided to members of the cooperative before agreements for land use and sludge delivery could be negotiated to insure a potential positive economic return with minimal problems.

Governmental Agencies and Regulation

Recently special provisions in federal legislation under Public Law 92-500 (Water Pollution Control Act Amendments of 1972) have made land treatment of wastewater a significant alternative which municipalities should consider because of renovation capabilities and cost effectiveness. The law is a combination of coercive legislation and incentive funding to achieve the objective of eliminating the discharge of pollutants into navigable waters by 1985. The law also calls for public owned treatment plants to upgrade to at least secondary treatment processes by mid-1977. The U.S. Environmental Protection Agency is the federal agency charged with the responsibility of executing the law and allocating matching grant funds to the states enabled by the law and appropriated by the U. S. Congress.

Grants to state and local agencies now encourage renovation of wastewater and sludges on land as provided under subsection 20(d) of the 1972 Amendments. Encouragement of wastewater treatment management that results in the construction of revenue producing systems and recycling of wastewater and sludges through agricultural production processes which are not harmful to the environment is now part of the grant provisions of the Act (15). The grant program is designed to assist municipalities with 75% federal grant funds, leaving 25% as the local share of investment.

Acquisition of land sites which are an integral part of the treatment system (excluding land used for sanitation buildings and treatment plants) is authorized by other sections of the Amendments and is included in cost sharing. Federally funded grants are available for all secondary and tertiary treatment systems providing such systems are the most practical from an operational viewpoint and subject to demonstrations that such systems are most cost effective as outlined by section 212(2)(c) of the 1972 Amendments (12).

Municipal officials have to be aware of state agencies and regulations as well as federal provisions. Indeed, it is the state agency with which municipal officials will work most directly to initiate and implement land treatment systems. Generally a specific water quality, pollution control, or intergovernmental relations division of these agencies is set up to work directly with community officials on matters pertaining to wastewater treatment.

Traditionally state agencies maintain control of water resources which are not under the navigable waters control powers belonging to federal jurisdiction. However, very few states in the North Central Region have specific statutes and regulations pertaining to the application of wastewater and sludge on land, although this status is changing rapidly. Some states have informal guidelines for wastewater treatment in general, while others approve of various systems in compliance with the federal regulations as reviewed by the state agencies. Currently, it is the best practicable criterion (operational practicality and most cost-effective) interpretation of subsections 201(d) and 212(2)(c) of Public Law 92-500 which have moved municipalities and state agencies to consider the land treatment alternative.

Other legal restraints with which municipalities should be familiar are regulations restricting the use of condemnation powers, acquiring easements, and contractual agreements. Municipalities must have the authority or work in cooperation with the appropriate governmental agency to acquire interest in land outside their jurisdictions. Such authority or interest is usually restricted by state law. Authority may be changed if a municipality is included in a sanitary district; *i.e.*, extra community powers are enjoyed by such authorities. This is the case in Illinois, Michigan, Ohio, and Wisconsin.

Public Acceptability

Acceptance or rejection of the land treatment concept by a particular community and/or extra-community involved is based primarily on two elements of concern: economy and health. Economic concerns are based upon the perception by landholders or their neighbors of outside factors which might result in positive or negative economic effects when wastewater and sludges are renovated within their community.

Such outside factors may include loss of property values, loss of community tax base, fear of odors, and others.

Health concerns are basic to everyone and can arouse even those individuals who are otherwise indifferent to normal community affairs. It is easy for even small groups of opponents to cause public controversy by raising doubts, founded or unfounded, about the operation of a land treatment system and its impact on human health. Such doubts are often resolved in favor of existing or conventional treatment systems which are sometimes much more expensive and sometimes provide even less protection of health. Negotiations within a community will surely break down if current agricultural production systems are greatly altered at a higher cost and information about potential health problems remains vague.

Important Factors Influencing Public Acceptability

A number of factors are of particular importance in destroying the opportunity for favorable public acceptance of a land treatment system.

- Implementing a land treatment project without presenting the known facts to everyone concerned about the operation of the system (economics, health, or risk of nuisances) is inviting failure. It should also be noted that providing such information will not insure acceptability. However, previous social research and experiences in the water resource development area suggest that perception of the rationale for the proposed project is an important factor in determining the reaction of individuals to both the project and municipal officials and agencies involved.

- The magnitude of community resistance varies directly with the magnitude of economic disruption and population relocation. This suggests that land acquisition by outright purchase should seek very large tracts from a minimal number of rural landholders. However, this works against minimizing economic disruption because such an action imposes serious income redistribution in rural areas between landholders and others receiving income from rural enterprises.

- Localized neighborhood resistance at the site other than from the landowners will most generally exist either for economic or health reasons. Such attitudes will often generate widespread public controversy and must be counteracted by accurate information and community education.

- Renovation of a municipality's wastewater and/or sludge involving land in another political jurisdiction may present additional problems. First, voter indifference in these jurisdictions may delay the decision-making process. Second, the concerns with economic health or nuisance problems may be magnified in these jurisdictions and result in outright rejection of the idea of land treatment.

- If farming practices are to be changed greatly and/or profits reduced by applying wastewater or sludges to land, there will often be no basis for mutual negotiations between farmers and municipal officials. In the Corn Belt, for example, a change from an intensive corn-soybean enterprise to a grassland-beef enterprise would mean reduced profits under current economic conditions and would not be acceptable. However, some farmers may choose to cease intensive production activities and find that engaging solely in the supply of use rights to municipalities is a profitable and desirable alternative.

- Generally large land application projects are more likely to fail because they are more difficult to control physically or economically.

• Excess water is a problem in all but the Western North Central states and limits farmer acceptability of the quantities of wastewater deemed economical and necessary by the municipality. These differences in opinion should be reconciled before plans are made.

Initial Approaches to Obtain Acceptability

The concerns and restraints mentioned above make it imperative that municipalities purposely plan steps to gain public acceptability in the initial stages of development of a land treatment system. A number of important steps are discussed below.

• It is important to inform farmers, their representatives, other governmental agencies, the press, and homeowners about the known effects of land treatment, both beneficial and detrimental, including legal information about land acquisition.

• Municipalities must work out the details of legal restraints within which land treatment can be operative.

• Municipalities should avoid the negative reactions associated with premature announcements that large acreages are proposed to be used for treatment prior to announcements about the sewage problem and the land treatment alternatives. Farmers and other groups should be informed about the operation of the system and its land requirement given the sewage load of the municipality.

• If the decision has been made to purchase the necessary land, do not schedule to purchase or obtain use-right arrangements immediately. Rather, a schedule of land acquisition should be set up over 2 to 5 years. A contract arrangement with one or two farmers in the initial year could be made (or a farm unit purchased) and the unit could be set up as a demonstration and monitoring site for public view and to work on minimizing the uncertainities before pushing ahead with larger acreages.

• Municipalities should consider operation of land treatment systems with a wide variety of land acquisition arrangements, ranging from purchase of tracts offered for sale over time, use-right arrangements with a fee, use of land other than agriculture to direct opposite negotiations; *i.e.*, bid by farmers to acquire wastewater and sludge on their farms. The systems should be flexible with respect to wastewater and sludge application rates and terms of contract, which might require planning for increased storage at the treatment plant or at some station point near land sites. Operation agreements should also be flexible in order to stimulate new technology with lower costs of operation.

• The municipality should be certain that net costs not be transferred from the sewage generating region to the recipient region. If this occurs, a form of compensation will have to be paid in addition to the use-right fee.

• Different community decision-making units may have to either be brought together (county, municipality, and farmers) or re-arranged so that representatives of the agricultural sector, homeowners, county and municipal officials all have participation in the decisions involving land treatment. This is a form of internalizing the public acceptance problem. In such cases each voter has some stake in the decision and bargaining positions can be expressed and made known to municipal officials.

• Land purchase or the "city farm" arrangement is often desirable for a municipality because it allows better control of the system. However, the arrangement is often viewed negatively by the public and results in land being taken from the tax rolls. Use-right arrangements, or better still, bidding by farmers to receive the nutrients are better arrangements for public acceptability, but result in weakened municipal control and contract terms.

• Continual conversion of uncertainties of the system into known facts aids decision making, lowers costs, and increases acceptability. Acceptability is also enhanced if knowledge of this conversion is widespread among various groups who must interact on public service delivery decisions, including farmers and others interested in the rural scene.

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Section 11

SITE MONITORING CONSIDERATIONS for Sludge and Wastewater Application to Agricultural Land

Paul A. Blakeslee

Monitoring in the broad context includes observation of system performance, checking the quality of affected natural systems, and observing and recording environmental impacts as quality changes occur. The role of monitoring in land application systems should be that of confirming the predictions and judgements made during the project development and design stage with respect to these systems. It should be employed as a tool in expanding understanding of system performance, not as a substitute for the fullest reasonable understanding of the many interrelated physical, chemical, and hydrologic factors within any project prior to implementation.

The project designer must consider the impact of three basic factors on the natural system when developing a wastewater or sludge application proposal in order to predict project success. The factors for prime consideration are:

- Public health impact through disease transmission
- Toxic materials and their impact
- Nitrogen compounds and their impact on ground and surface water sources.

The objectives of system monitoring can be fulfilled by developing a monitoring program which considers:

- Applied wastewater and/or sludge characteristics
- Soil characteristics
- Groundwater and surface water quality
- Quality of vegetation produced.

The costs of an effective monitoring program should be incorporated into the routine and ongoing costs of operation of the unit generating the wastewater or sludge to be treated or used in an on-land application program. It may be possible to develop a full monitoring program including all sampling and testing capability within the normal operations of the generating unit where a large scale operation is involved. For smaller projects, the specialized testing methods to be employed may require the use of Cooperative Extension Service and/or commercial testing services.

Wastewater and/or Sludge Characteristics

The wastewater or sludge to be applied at a site is like the raw material in a manufacturing process. To be assured of an acceptable end product, *i.e.*, crop, enriched soil, or other benefit to the system, the raw material must be of consistent, known, and acceptable quality. The recommended analyses have been covered in Sections 3 and 6.

Soil Characteristics

The characteristics of the soil system employed for treatment should have been fully established during project design and the monitoring program developed should identify changes in these characteristics to avoid permanent or irreversible soil system damage. Samples of the untreated soil should be collected and retained for future testing. The concentration of applied trace elements in the soil and where possible the available chemical form of such materials should be routinely determined. The frequency of such determinations may vary from project to project, with the monitoring frequency being adjusted to the rate of change observed and project scope. In cases where domestic wastewater or sludge with little industrial waste present is applied, annual sampling may be sufficient.

Common groupings of elements which should be considered for soil monitoring can be determined from the composition of the waste material. These may include:

- Cadmium, chromium, copper, lead, nickel, and zinc

- Mercury, arsenic, chromium, and boron.

If other potentially harmful metals or organics are present in the wastewater or sludge, the testing program should be expanded to include them.

Groundwater Monitoring

Monitoring wells must be designed and located to meet the specific geologic and hydrologic conditions at each site. Consideration must be given to the following:

- Geological soil and rock formations existing at the specific site

- Depth to an impervious layer

- Direction of flow of groundwater and anticipated rate of movement

- Depth of seasonal high water table and an indication of seasonal variations in groundwater depth and direction of movement

- Nature, extent, and consequences of mounding of groundwater which can be anticipated to occur above the naturally occurring water table

- Location of nearby streams and swamps

- Potable and non-potable water supply wells

- Other data as appropriate.

It may be necessary to establish site groundwater conditions through installation of a series of simple observation wells prior to the actual selection of locations and depths for permanent monitoring wells. Groundwater quality should be monitored immediately below the water table surface near the site. As distance from the site increases, the depth of sample withdrawal from within the groundwater system may need to be increased or sampling at multiple depths may be required to assure interception of affected groundwater. Monitoring wells must be located so as to detect any influence of wastewater application on the groundwater resources.

Water level measurements should be accurate to 0.01 feet (1/8 inch) and referenced to a permanent reference point, preferably U.S. Geological Survey datum. Measurements should be made under static water level conditions prior to any pumping for sample collection. All monitoring wells should be securely capped and locked when not in use to avoid contamination.

To establish a suitable data base for reference to background conditions, a minimum of three monthly samples should be collected from each monitoring well prior to placing the on-land application system in operation. In cases where background water quality adjacent to the site may be influenced by prior waste applications, provision of monitoring wells or analysis of water quality from existing wells in the same aquifer beyond the area of influence will be necessary.

Samples should be collected monthly during the first 2 years of operation. After the accumulation of a minimum of 2 years of groundwater monitoring information, modification of the frequency of sampling may be considered. The following sampling procedures should be employed:

- A measured amount of water equal to or greater than three times the amount of water in the well and/or gravel pack should be exhausted from the well before taking a sample for analysis. In the case of very low permeability soils, the well may have to be exhausted and allowed to refill before a sample is collected.
- Pumping equipment should be thoroughly rinsed before use in each monitoring well.
- Water pumped from each monitoring well should be discharged to the ground surface away from the wells to avoid recycling of flow in high permeability soil areas.
- Samples must be collected, stored, and transported to the laboratory in a manner to avoid contamination or interference with subsequent analyses. (See Section 6.)

Sample Analysis

Water samples collected for background water quality at wastewater application sites should be analyzed for the following: (Note: Parameters for groundwater monitoring at sludge application or industrial waste application sites are similar. Additional analyses may be necessary and should be determined on an individual basis depending on the composition of the wastes applied.)

- Chloride
- Specific conductance
- pH
- Total hardness
- Alkalinity
- Ammonia nitrogen
- Nitrate nitrogen

TABLE 11.1--Probable Available Form, the Average Composition Range for Selected Agronomic Crops, and Suggested Tolerance Levels of Heavy Metals in Agronomic Crops When Used for Monitoring Purposes.

	Probable Available Form	Common Average Composition Range* ppm	Suggested Tolerance Level ppm
		Cations	
Barium	Ba^{++}	10-100	200
Cadmium	Cd^{++}	0.05-0.20	3
Cobalt	Co^{++}	0.01-0.30	5
Copper	Cu^{++}	3-40	150
Iron	Fe^{++}	20-300	750
Manganese	Mn^{++}	15-150	300
Mercury	Hg^{++}	0.001-0.01	0.04
Lithium	Li^{+}	0.2-1.0	5
Nickel	Ni^{++}	0.1-1.0	3
Lead	Pb^{++}	0.1-5.0	10
Strontium	Sr^{++}	10-30	50
Zinc	Zn^{++}	15-150	300
		Anions	
Arsenic	AsO_4^-	0.01-1.0	2
Boron	HBO_3^-	7-75	150
Chromium	CrO_4^{3-}	0.1-0.5	2
Fluorine	F^-	1-5	10
Iodine	I^-	0.1-0.5	1
Molybdenum	MoO_4^-	0.2-1.0	3
Selenium	SeO_4^-	0.05-2.0	3
Vanadium	VO_3^-	0.1-1.0	2

*Average values for corn, soybeans, alfalfa, red clover, wheat, oats, barley, and grasses grown under normal soil conditions. Greenhouse, both soil and solution, values are omitted.

Values are for corn leaves at or opposite and below ear leaf at tassel stage; soybeans, the youngest mature leaves and petioles on the plant after first pod formation; legumes, upper stem cuttings in early flower stage; cereals, the whole plants at boot stage; and grasses, whole plants at early hay cutting stage.

- Nitrite nitrogen
- Total phosphorus
- Methylene blue active substances
- Chemical oxygen demand
- Any heavy metals or toxic substances found in the applied wastes.

After adequate background water quality information has been obtained, a minimum of one sample per year, obtained at the end of the irrigation season in the case of seasonal operations, should be collected from each well and analyzed for the above constituents.

All other water samples should be analyzed for chlorides and specific conductance as indicators of changes in groundwater quality resulting from the waste applied. If significant changes are noted in chloride and/or specific conductance levels, samples should immediately be analyzed for the other parameters listed above to determine the extent of water quality deviation from background levels.

Vegetation Monitoring

The vegetation produced on a wastewater or sludge application site may be the most sensitive and meaningful monitor of the impact of materials applied to the site. Uniform analytical procedures should be used. Similarly, uniform selection of the portion of the plant to be analyzed should be used so that the information obtained from a given site is readily comparable with other systems. (See footnote to Table 11.1.) The values in Table 11.1 have been suggested (18) as common average composition and suggested tolerance levels for monitoring purposes.

The tolerance levels suggested in Table 11.1 for agronomic crops are generalized concentrations averaged over many crops. They are one-half less than the values which are: toxic to animals, plant levels at which appreciable transfer of the element from the vegetative portion of the plant to the grain occurs, and/or the level known to be toxic to the plant itself. Therefore, the tolerance levels allow for some elemental increases in the vegetative portion of plants without significant increases in seed grain or immediate food chain hazards. Levels are intended only for grain crops or hay for animals. Vegetable crops are excluded. The tolerance levels do not apply to crops where the vegetative portion of the plant may be consumed by humans.

Sampling and Analysis Methods

To permit effective comparison of monitoring data obtained over a period of time at a wastewater or sludge application site, or to permit the comparison of data from one site with another, it is essential to use uniform sampling and analysis techniques wherever possible. A bulletin entitled Sampling and Analysis of Soils, Plants, Wastewater and Sludges: Suggested Standardization and Methodology, NC-118, North Central Regional Publication No. 230 (20), has been developed for this purpose.

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Section 12

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Section 13

GLOSSARY OF TERMS

Acre inches/year -- The amount (inches) of water or effluent spread on 1 acre of land in 1 year.

Activated sludges -- Sludge floc produced in raw or settled wastewater by the growth of zoogleal bacteria and other organisms in the presence of dissolved oxygen and accumulated in sufficient concentration by returning floc previously formed. Product is waste-activated sludge.

Adsorbed - adsorption -- The attraction of ions or compounds to the surface of a solid. Soil colloids adsorb large amounts of ions and water.

Aeration -- The process by which air in the soil is replaced by air from the atmosphere.

Aerobic -- (i) Having molecular oxygen as a part of the environment. (ii) Growing only in the presence of molecular oxygen.

Aerobic sludge digestion -- Digestion of organic waste solids by means of aeration.

Aerosols -- Microscopic droplets dispersed in the atmosphere.

Agronomic -- Crops having economic importance in agriculture.

Alkalinity -- A soil or material with pH of 8.5 or higher, or with a high exchangeable sodium content (15% or more of the exchange capacity).

Anaerobic -- The absence of molecular oxygen. Living or functioning in the absence of air or free oxygen.

Anaerobic digested sludge -- The stabilization of organic waste solids brought about through the action of microorganisms in the absence of elemental oxygen.

Annual crop -- A crop which completes its entire life cycle and dies within 1 year or less; *i.e.*, corn, beans.

Aquifer -- Stratum below the surface capable of holding water.

Arid -- Dry; limited moisture.

Available moisture -- The portion of the soil water readily available for plant use.

Basin irrigation -- An efficient system of irrigating in which a field or orchard is divided into basins which are filled with water.

Best practicable treatment -- Referring to sewage treatment as the most operational treatment system given local conditions and wastewater content.

Biological treatment -- Forms of wastewater treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Intermittent sand filters, contact beds, trickling filters, and activated sludge processes are examples.

BOD -- Biochemical Oxygen Demand. A standard test used in assessing wastewater strength. The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions.

BOD_5 -- 5-day Biochemical Oxygen Demand. The quantity of oxygen used in the biochemical oxidation of organic matter after 5 days, at a specified temperature, and under specified conditions.

Bulk density -- The mass of dry soil per unit bulk volume including the air space. The bulk volume is determined before drying to constant weight at 105^{o} C.

Bunchgrass -- Bunchgrasses lack stolons and form thick bunches such as fescue and wheat grass.

Calcareous -- Soil containing sufficient calcium carbonate to effervesce visibly when treated with cold 0.1 $\underline{N}$ hydrochloric acid.

Carbonate -- A compound containing the radical CO_3^{-2}.

Cation exchange capacity -- The sum total of exchangeable cations a soil can adsorb. Expressed in milliequivalents per 100 grams of soil or other adsorbing material such as clay.

Central pivot system -- An irrigation system in which a lateral line supported by towers rotates about a pivot point.

Chelating properties -- The property of certain chemical compounds in which a metallic ion is firmly combined with the compound by means of multiple chemical bonds.

Clay -- Soil particles less than 0.002 mm in diameter.

Closed drainage system -- A landscape where essentially all the products derived within the perimeter are trapped within the system and are not transmitted to streams or water supplies.

COD -- Chemical Oxygen Demand. The oxygen consumed by the chemical oxidation of material in water.

Composite -- To make up a sample of distinct portions so the sample is representative of the total material being sampled rather than any single portion.

Conducting layers -- Layers of soil which contain the property of enabling water and fluids to pass through with little resistance.

Cost effectiveness -- The least cost project or means to achieving a specific goal.

Cover crop -- A crop grown between periods of regular crops for adding organic matter to soil, and/or protection against erosion.

Denitrification -- The biochemical reduction of nitrate or nitrite to gaseous nitrogen either as molecular nitrogen or as an oxide of nitrogen.

Detritus -- Any disintegrated material resulting from a larger material being rubbed or worn away; debris.

Drilled -- Those seeds or crops which have been planted in rows by means of a drill.

Easement, use right -- A right afforded a party to make limited use of another party's real property.

Effluent -- The liquid substance, predominately water, containing inorganic and organic molecules of those substances which do not precipitate by gravity.

Electrical conductivity -- An expression of the readiness with which an electrical impulse (generated by ionic activity) flows through a water or soil system.

Electrode method -- A method of analysis by use of electrodes for measuring various substances.

Ensiling -- The process of placing green plant material in a silo, pit, trench, or stack for fermentation and storage.

EPA -- Environmental Protection Agency.

Eutrophication -- The process in which the rate of plant growth is faster (due to the presence of an abundant supply of nutrients) than the rate of decomposition.

Evapotranspiration -- The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and by transpiration from plants.

External force -- In the economic sense, a force externally imposed by one economic agent on other economic agents. Such forces involve costs and/or benefits and are sometimes referred to as externalities or spillover effects.

Fecal coliforms -- A type of facultative, anaerobic, Gram-negative, rod-shaped cells of nonspore-forming bacteria originating from fecal material.

Fee simple -- An estate in land having unqualified ownership and power of disposition.

Fescue pastures -- Pastures or tracts of land used for grazing which consist of the species of grass of the genus *Festuca*, family *Gramineae*.

Forage crop -- A crop such as hay, pasture grass, legumes, etc. which is grown primarily as forage or feed for livestock.

Friable condition -- A soil with aggregates which can be readily ruptured and crushed with application of moderate force. Easily pulverized or reduced to crumb or granular structure.

Furrow irrigation -- A method of irrigating in which water is run in small ditches, furrows, or corrugations, usually spaced close enough together to afford lateral penetration between them.

Geologic -- Related to or based on geology or the properties of the earth surface and subsurface soil and rock formations.

Glacial outwash -- Stratified glacial drift which is water built. The material is arranged in layers of material of different texture.

Glacial till -- The unconsolidated, heterogeneous mass of clay, sand, pebbles, and boulders deposited by receding ice sheets.

Grab sample -- A sample obtained randomly at one time. This may or may not be representative of an entire composite of samples.

Groundwater quality -- The degree of purity of the water obtained from the zone of saturation (well water, subsurface or underground water).

Groundwater recharge -- Return of surface water to groundwater aquifers.

Heavy metals -- Generally, those elements in the periodic table of elements which belong to the transition elements. They may include essential micronutrients and other nonessential elements.

Holding basin (storage lagoon) -- A natural or artificially created space which has the shape and character of confining material enabling it to hold water. It may contain raw or partially treated wastewater in which aerobic or anaerobic stabilization occurs.

Host-specific pest -- A parasite or pest which can live in only one host, to which it is therefore said to be specific.

Humid areas -- Geographic areas where the climate has sufficient precipitation to support a forest vegetation. Precipitation may range from 20-60 inches annually.

Humus (residual humus) -- Organic matter in the soil which has reached an advanced stage of decomposition and has become colloidal in nature. It is usually characterized by a dark color, a considerable nitrogen content, and chemical properties such as a high base-exchange capacity.

Hydraulic capabilities -- Fluids, usually water, which are moving or at rest under forces of gravity or pressure.

Hydrologic -- Relating to the properties and movement of water within a soil system and the underlying rock formations.

Immobilized -- The action or reaction by which a substance (element) is rendered immovable; fixed, as by organic matter or clay.

Impermeable pans -- Zones within the soil which restrict the movement of gases, liquids, and roots.

Impervious -- Resistant to penetration by fluids or by roots.

Industrial organics -- Materials such as pesticides, chlorinated plasticizers, fire retardants, etc.

Infiltration capacity -- The maximum rate at which a soil, in a given condition at a given time, can absorb water, commonly expressed in inches of depth per hour.

Interlacing rhizomes -- The crossing and interwoven stems which grow partly or entirely beneath the surface of the ground, often having scale-like leaves.

Interstratified bedrock -- Alternating layers of different bedrock; layers occurring between beds of different material.

Knifing -- The injection of a substance below the soil surface.

Leaching -- The removal of soluble constituents from soils or other materials by percolating water.

Loading parameter -- Variables such as water, metals, soluble salts, suspended solids, nitrogen, or phosphorus which may limit wastewater or sludge application.

Lodging -- Pertaining to field crops -- to break, bend over, or lie flat on the ground, sometimes forming a tangle. Lodging may be caused by high nitrogen levels in the soil, lush growth, wind and heavy rain, and plant diseases.

Loess -- A massive deposit of silt (tan or buff colored), with particles typically angular and uniform in size. It is usually calcareous, often contains concretions of calcium carbonate and shows lamination or bedding.

Major nutrient (macronutrient) -- A chemical element necessary in large amounts (usually > 1 ppm in the plant) for the growth of plants; *i.e.*, nitrogen, phosphorus, potassium.

Matrices -- That which gives origin or form to a thing, or serves to enclose it.

Metal toxicities -- Toxicities arising from too high levels of metals in the soil. These could be due to cadmium, nickel, zinc, copper, etc. at such levels that they cause stunted or reduced growth and micronutrient imbalances within the plant.

Methylene blue active substances -- A measure of the amount of anionic surfactants (detergents) present in water.

MGD -- Millions of gallons per day.

Micronutrient -- A chemical element necessary in only extremely small amounts (< 1 ppm in the plant) for growth of plants; *i.e.*, B, Cl, Fe, Mn, Mo, Zn, Cu.

Microorganism -- An organism so small it cannot be seen clearly without the use of a microscope.

Mineralized -- The conversion of an element in organic combination to its inorganic form as a result of microbial decomposition.

Monoculture -- Cultivation of a single crop, such as wheat or cotton, to the exclusion of other possible uses of the land.

Mulch -- Soil, straw, peat, or any other loose material placed on the ground to conserve soil moisture, or prevent undesirable plant growth or soil erosion.

NC-98 -- North Central Regional Committee of the State Agricultural Experiment Stations and Cooperative State Research Service titled "Environmental Accumulation of Nutrients as Affected by Soil and Crop Management."

NC-118 -- North Central Regional Committee of the State Agricultural Experiment Stations and Cooperative State Research Service titled "Utilization and Disposal of Municipal, Industrial and Agricultural Processing Wastes on Land."

Ponding -- The accumulation of free water on the soil surface.

Potable -- Water suitable for drinking.

Precipitated -- To separate out in solid form from a solution.

Precipitation surpluses -- Excessive rainfall.

Primary sludge (raw sludge) -- Sludge obtained from a primary settling tank, which is the first settling tank for removal of settleable soils through which wastewater is passed in a treatment work.

Putrescible wastewater constituents -- Microbially decomposed in the absence of oxygen.

Renovation - renovated water -- Water which has undergone treatment through chemical or biological means whereby impurities have been removed, thus making it more desirable for a particular use.

Risk statement -- A statement of probability with reference to the probability of occurrence, impact, and duration of an event.

Row crop -- A crop such as corn, beans, sugar beets, cotton, etc., usually grown or cultivated in rows.

Runoff -- That portion of total precipitation finding its way into drainage channels. It consists of ever varying proportions of both surface runoff and groundwater runoff.

Sand -- Soil particles between 2 and 0.005 mm in diameter.

Secondary treatment -- The treatment of wastewater by biological methods after primary treatment by sedimentation.

Sedimentation -- Deposit of sediment by natural or mechanical means.

Seeps -- A spot where water oozes out slowly from the soil and gathers in a pool or produces merely a wet place, usually on a hillside as a hill base.

Selective breeding -- The breeding of selective plants or animals chosen because of certain desirable qualities or fitness, as contrasted to random or chance breeding.

Semi-arid -- The climate, characteristic of the regions intermediate between the true deserts and subhumid areas, under which precipitation effectiveness is such that a vegetation of scattered short grasses, bunchgrasses, or shrubs prevails.

Shallow discing -- The process by which debris is chopped into pieces and put under the soil by use of a disk, normally less than 5 inches.

Shrink-swell potential -- The potential of a soil material to change volume as a result of wetting or drying.

Side roll laterals -- Laterals used in irrigating low-growing row crops and forages. They are mounted on wheels with the pipeline as the axle. A length of flexible hose is used to make the connection to the main line.

Silt -- Soil particles between 0.05 and 0.002 mm in diameter.

Soil compaction -- The process by which soil grains are rearranged to decrease void space and bring them into closer contact with each other, thereby increasing the weight or bulk material per cubic foot.

Soil horizon -- A layer of soil approximately parallel to the land surface and differing from adjacent genetically related layers.

Soil profile -- A vertical section of the soil from the surface through all its horizons, including C horizons.

Soil structure -- The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Sod former -- Any crop or vegetative cover which quickly forms a heavy, close-knit, top growth over the surface of the soil and a root system which binds the soil particles together, thus forming a sod, such as white clover or bluegrass.

Specific conductance -- A measure of the capacity of water to convey an electrical current. This property is related to the total concentration of ionized substances in a water and changes in the specific conductance at a given monitoring well location give an indication of a change in groundwater quality.

Sprinkler irrigation (spray irrigation) -- Irrigation by means of above-ground applicators which project water outward through the air, making it reach the soil in droplet form.

Static water level -- Equilibrium water level reached in an observation or monitoring well after an extended period.

Strata -- Layers or beds of rock.

Structural carbon -- Structural forms of most organic molecules are made up of a carbon skeleton with other elements bonded to it.

Submarginal land -- Land incapable of sustaining a certain use or ownership status economically.

Substratum -- The C horizon of a soil.

Surface irrigation -- Irrigation distribution of water over the soil surface by flooding or in furrows for storage in the soil for plant use.

Suspended solids -- Solid particles which do not precipitate out of solution or do not easily filter out. They may be colloidal in nature.

Texture (soil texture) -- The relative proportion in a soil of the various size groups of individual soil grains (sand, silt, and clay).

Tight subsoil -- A subsoil which is very compact and permits only very slow movement of water.

Tillage operations -- Working the soil to bring about more favorable conditions for plant growth.

Tolerance level -- The highest level an organism can resist or endure before becoming affected.

Toxic trace organics -- See industrial organics.

Trickling filter -- A bed of crushed stone, gravel, or cinders of relatively large size and usually about 5 feet or more thick. Sewage is applied at the surface and the solids precipitate out during their descent through the bed. Aerobic bacteria decompose the solids.

Uncertainty -- Usually refers to an event about which nothing is known with respect to impact, duration, and probability of occurrence.

Underdrainage -- That drainage consisting of drain tiles placed in trenches deep enough to allow the covering soil to be cultivated and the profile adequately drained.

Uptake -- The process by which plants take elements from the soil. The uptake of a certain element by a plant is calculated by multiplying the dry weight by the concentration of the element.

U.S.G.S. datum -- Elevation relative to mean sea level established by the United States Geological Survey. United States Geodetic Survey.

Vacuum filtration -- Separation of substances by use of a filtering system with the aid of a vacuum.

Volatilization - vaporization -- The conversion of a liquid or solid into vapors.

W-124 -- Western Regional Committee of the State Agricultural Experiment Stations and Cooperative State Research Service titled "Soil as a Waste Treatment System."

Water table -- The upper surface of groundwater or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to the atmospheric pressure.

Wastewater loadings -- The amount of wastewater applied per acre per unit of time.

Watershed -- The total runoff from a region which supplies the water of a river or lake; a catchment area or drainage basin.

Yield goals -- The highest anticipated or expected yield a field should produce.

Section 14

APPENDICES

Appendix A

Double Ring Infiltrometer Method for Measuring Soil Infiltration Rates

Ref.: Bertrand, A. R. 1965. Rate of Water Intake in the Field. *In* Methods of Soil Analysis, Part 1, Monograph No. 9, American Society of Agronomy, Madison, Wis.

Needed equipment and supplies:

1. *Metal cylinders:* Prepare three to preferably five cylinders for use in a single test, using smooth, cold-rolled steel or galvanized steel of thickness not to exceed 0.08 inch (approximately 14 gauge) unless a sharpened cutting edge is provided. Make the length at least 10 inches and preferably 12 to 14 inches. Make the inside diameter at least 12 inches and preferably more, making the diameters such that the cylinders will nest inside each other if desired. Butt-weld the longitudinal seams, and grind them to a reasonably smooth finish. If a set of buffer cylinders is to be used instead of an earthen dam to provide a buffer compartment, make these cylinders in the manner described above; but use 10-gauge or heavier metal, use a length of 8 inches, use a diameter at least 8 inches larger than the measuring cylinders, and weld a reinforcing strip around the top.

2. *Driving plate:* Use a piece of steel plate at least 1/2 inch thick and from 2 to 4 inches larger than the diameter of the largest measuring cylinder. Weld lugs to the lower face to keep the plate approximately centered on the cylinders. If desired for greater ease in carrying the plate, weld a handle of steel rod 1/2 inch in diameter to one edge.

3. *Driving hammer:* A 16-lb. sledge hammer, used with a tamping blow rather than a swinging blow, is adequate for many soils. To make a heavier and better hammer, attach a handle to one edge of a steel block weighing about 30 lb. (this weight is provided by a block having dimensions about 8 by 2 inches). Alternatively, attach a 1-1/4 inch by 3 inch, banded, malleable-iron reducer to a 4-foot length of standard 1-1/4 inch galvanized pipe, and fill the reducer and pipe with 15 to 20 lb. of lead.

4. *Water supply:* Use 50-gallon steel drums, 10-gallon milk cans, or other suitable containers for transporting water to the site of the measurements. Use one or more buckets of 10 to 12-quart capacity to convey water to the cylinder. Employ water suitable for irrigation.

5. *Puddling protection device:* Use a piece of folded burlap, cloth, heavy paper, or loosely fitting 1/4-inch board inside the central cylinder to protect the soil surface from puddling when water is first applied.

6. *Timing device:* Use a watch or other timepiece which can be read to 1 minute or less.

7. *Hook gauge:* Grind a 16-inch length of welding rod to a fine point at one end, and bend this end through 180° to form a hook in which the pointed end is parallel with the long axis of the rod. Solder a flat piece of brass about 3/4 by

1/4 by 1/16 inch in size to the welding rod about 3 inches from the end opposite the hook, placing the long dimension of the brass piece perpendicular to the axis of the welding rod. Use this assembly in connection with a triangular engineer's scale to measure the distance of the water surface in the cylinder below a reference point. Alternatively, use the manometer described below in 8 or the constant-head device in 9.

8. *Manometer:* As an alternative to the hook gauge for measuring the level of water inside the central cylinder, prepare a manometer in the following manner. Secure a graduated pipette of perhaps 30 cm. length and several millimeters inside diameter, and cut off the lower restricted end. Then cut a piece of 2 by 12-inch board in the shape of a right triangle with one angle of about 30° and and with the hypotenuse of a length slightly greater than that of the graduated pipette. Fasten the pipette to the edge of the triangle which forms the hypotenuse, and fasten the side which forms the other leg of the 30° angle to a triangular piece of 1/4-inch steel plate which is set on three leveling pins and is placed outside the infiltrometer. Before each use, carefully level the platform. Before adding water to start the infiltration run, attach one end of a piece of flexible tubing to the bottom of the pipette, and lead the other end over the top of the two cylinders to the bottom of the inner cylinder. Immediately following addition of water to the inner cylinder, suck on the top of the pipette to cause water to fill the flexible tube. Then read the position of the meniscus on the pipette scale, and multiply the values by the appropriate factor to obtain readings of vertical movements of the water surface in inches or centimeters as desired. The conversion factor will remain the same as long as the platform is accurately leveled.

9. *Constant-head device:* If a constant head is to be maintained in the cylinder, connect the main water supply tank to a float valve attached to the side of the measuring cylinder (or to a stake if the furrow or basin method is used). Use a siphon tube of sufficient size (usually 1/2-inch diameter) to make the connection.

Procedure:

Select a general area that is representative for the purpose of the measurement. Examine and describe the soil profile conditions of texture, structure, water content, and adsorbed sodium, with particular reference to the first foot. Secure samples for measuring the adsorbed sodium content (where sodium may be a problem) and the water content. Record the kind of crop and the stage of growth, and describe any surface litter or mulch and the condition of the soil surface -- freshly cultivated, cloddy, crusted, cracked, etc. Make note of any other condition observed which might have an influence on rate of water intake.

To provide for concurrent measurements on three or more sites, select the exact sites for the measurements within a limited area, normally 1/2 acre or less. Unless the objective is to make measurements of special conditions, avoid areas which may be affected by unusual surface disturbance, animal burrows, stones which might damage the cylinder, animal traffic, or machine traffic.

Set a cylinder in place and press it firmly into the soil. For cylinders less than 24 inches in diameter, place the driving plate on the cylinder, stand on the plate, and drive the cylinder into the soil by tamping the plate with the driving hammer. Drive the cylinder in vertically, using a carpenter's level as needed. Do not drive the cylinder into the soil irregularly so that first one side and then the other goes down. This procedure produces a poor bond between the cylinder wall and the soil, and it disturbs the soil core within the cylinder. If the cylinder should enter the soil at an angle, remove it and reset it in another location. Drive the cylinder into the soil to a depth of approximately 4 inches.

Around the measuring cylinder, place a buffer cylinder having a diameter at least 8 inches greater. Drive this cylinder into the soil to a depth of 2 to 4 inches by tamping it around the circumference with the driving hammer. Strictly vertical movement of this cylinder into the soil is not particularly important. As an alternative to the buffer cylinder, construct a buffer pond by throwing up a low (3 to 6 inches) dike around the cylinder, avoiding disturbance of the soil inside the dike, and keeping the inside toe of the dike at least 6 inches from the cylinder.

Place burlap or other puddling protection device on the soil within the central cylinder. Then fill the buffer pond on the outside with water to a depth of about 2 inches, and maintain approximately the same depth throughout the period of observation. (The depth of water in the buffer pond is not critical as long as a supply of water is always available for infiltration into the soil.) Immediately after adding water to the buffer pond, fill the central cylinder with water to the desired depth (usually 1 to 3 inches), remove the puddling protection device, and make a measurement of the water surface elevation by a hook gauge (or manometer if desired). Use the cylinder edge for the reference level, and mark the cylinder so that all subsequent measurements can be made at the same point on the cylinder. Alternatively, if the basin or furrow method is used, employ a stake to provide a reference level. Record the hook gauge reading and the time at which the observation was made. Carry out these operations quickly, so that errors from intake during the operations will be small.

Make additional hook gauge measurements at intervals, and record the water level and the time. For most soils, observations at the end of 1, 3, 5, 10, 20, 30, 45, 60, 90, and 120 minutes, and hourly thereafter, will provide adequate information. Make observations more frequently as needed on soils having a high rate of intake. As a general rule, the intake between measurements should not exceed 1 inch. Continue measurements until the rate of intake is almost constant.

When the water level has dropped 1 or 2 inches in the cylinder, add sufficient water to return the water surface approximately to its initial elevation. Record the level and time just before filling and the level after filling. Keep the interval between these two readings as short as possible to avoid errors caused by intake during the refilling period. (In analyzing the results, the assumption is made that the refilling is instantaneous.)

If a constant water level in the cylinder or basin is maintained by a float valve, measure the rate of depletion of water in the supply tank by a hook gauge, manometer, or automatic water-stage recorder.

Robert Taft Sanitary Engineering Center Percolation Test

Ref.: U. S. Dept. of Health, Education and Welfare. 1967. Manual of Septic-Tank Practice. Public Health Service Publication No. 526, pp. 4-8.

Procedure:

1. *Number and location of tests:* Six or more tests shall be made in separate test holes spaced uniformly over the proposed absorption field site.

2. *Type of test hole:* Dig or bore a hole, with horizontal dimensions of 4 to 12 inches and vertical sides to the desired depth. To save time, labor, and volume of water required per test, the holes can be bored with a 4-inch auger.

3. *Preparation of test hole:* Carefully scratch the bottom and sides of the hole with a knife blade or sharp-pointed instrument, to remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Remove all loose material from the hole. Add 2 inches of coarse sand or fine gravel to protect the bottom from scouring and sediment.

4. *Saturation and swelling of the soil:* It is important to distinguish between saturation and swelling. Saturation means that the void spaces between soil particles are full of water. This can be accomplished in a short period of time. Swelling is caused by intrusion of water into the individual soil particles. This is a slow process, especially in clay-type soil, and is the reason for requiring a prolonged soaking period.

   In the conduct of the test, carefully fill the hole with clear water to a minimum depth of 12 inches over the gravel. In most soils, it is necessary to refill the hole by supplying a surplus reservoir of water, possibly by means of an automatic syphon, to keep water in the hole for at least 4 hours and preferably overnight. Determine the percolation rate 24 hours after water is first added to the hole. This procedure is to insure that the soil is given ample opportunity to swell and to approach the condition it will be in during the wettest season of the year. Thus, the test will give comparable results in the same soil, whether made in a dry or a wet season. In sandy soils containing little or no clay, the swelling procedure is not essential, and the test may be made as described under 5C, after the water from one filling of the hole has completely seeped away.

5. *Percolation rate measurement:* With the exception of sandy soils, percolation rate measurements should be made on the day following the procedure described under 4, above.

   A. If water remains in the test hole after the overnight swelling period, adjust the depth to approximately 6 inches over the gravel. From a fixed reference point, measure the drop in water level over a 30-minute period. This drop is used to calculate the percolation rate.

   B. If no water remains in the hole after the overnight swelling period, add clear water to bring the depth of water in the hole to approximately 6 inches over the gravel. From a fixed reference point, measure the drop in water level at approximately 30-minute intervals for 4 hours, refilling 6 inches over the gravel as necessary. The drop which occurs during the final 30-minute period is used to calculate the percolation rate. The drops during prior periods provide information for possible modification of the procedure to suit local circumstances.

C. In sandy soils (or other soils in which the first 6 inches of water seeps away in less than 30 minutes, after the overnight swelling period), the time interval between measurements should be taken as 10 minutes and the test run for 1 hour. The drop which occurs during the final 10 minutes is used to calculate the percolation rate.

Appendix B

Sample Calculations to Determine Sludge Application Rates on Agricultural Land (Section 3)

Sludge: 2% NH_4-N, 0% NO_3-N, 5% total N, 2% P, 0.2%K

Zn, 10,000 ppm; Cu, 1,000 ppm; Ni, 50 ppm; Pb, 5,000 ppm; Cd, 10 ppm

Soil: Silt loam, CEC = 20 meq/100 g; fertilizer recommendations from soil tests are 25 lb. of P per acre and 100 lb. of K per acre

Previous applications: 10 tons/acre for 2 previous years

From Table 3.4: 180 bu. corn -- 240 lb. N, 44 lb. P, 199 lb. K

A. Calculate annual rate based on N and Cd

1. Available N in sludge

   2% NH_4-N + 0% NO_3-N = 2% N_i

   5% total N = 2% N_i = 3% N_o

   $$\text{Lb. available N/ton sludge} = 20 \times 2\% + 4 \times 3\% = 40 + 12 = 52$$

   52 lb. available N/ton sludge

2. Residual N

   From Table 3.5 for 3% organic N

   a) Sludge added 1 year earlier

      10 tons/acre x 1.4 lb. N/ton = 14 lb. N

   b) Sludge added 2 years earlier

      10 tons/acre x 1.4 lb. N/ton = 14 lb. N

   c) Residual N = 28 lb.

3. Sludge Application Rate

   a) 240 lb. needed — 28 lb. residual = 212 lb. from sludge

   b) $\dfrac{212 \text{ lb. N}}{52 \text{ lb. N/ton sludge}}$ = *8.7 tons/acre*

   c) Calculate application rate for 2 lb. Cd/acre

      $\dfrac{2 \text{ lb. Cd/acre}}{10 \text{ ppm CD} \times .002}$ = tons/acre = *100 tons/acre*

4. The lower amount is applied = *8.7 tons sludge/acre*

B. Calculate total sludge amount which may be applied

Based on Table 3.3, maximum amounts are calculated as follows:

	Metal	Maximum Amount	Conc. in Sludge	Tons of Sludge/Acre	Calculation
		lb./acre	ppm		
1)	Pb	2000	5000	200	$= \frac{2000 \text{ lb. Pb/acre}}{5000 \text{ ppm Pb} \times .002}$
2)	Zn	1000	10,000	*50*	$= \frac{1000 \text{ lb. Zn/acre}}{10{,}000 \text{ ppm Zn} \times .002}$
3)	Cu	500	1000	250	$= \frac{500 \text{ lb. Cu/acre}}{1000 \text{ ppm Cu} \times .002}$
4)	Ni	200	50	2000	$= \frac{200 \text{ lb.Ni/acre}}{50 \text{ ppm Ni} \times .002}$
5)	Cd	20	10	1000	$= \frac{20 \text{ lb. Cd/acre}}{10 \text{ ppm Cd} \times .002}$

The lowest amount is from equation 2. Thus, sludge application is limited by Zn at *50 tons/acre*.

C. Calculate fertilizer needed

1. P fertilizer

   8.7 tons/acre x 2% P x 20 = 358 lb. P/acre

   Fertilizer recommendation is 25 lb. P/acre

   No fertilizer P needed

2. K fertilizer

   8.7 tons/acre x 0.2% K x 20 = 34.8 lb. K/acre

   Fertilizer recommendation is 100 lb. K/acre

   Fertilizer K needed = 65 lb./acre

Appendix C

Some Useful Factors and Conversions

1. 1 acre-inch of liquid = 27,154 gallons = 3,630 $ft.^3$ = 102,787 liters

2. 1 cm-hectare of liquid = 100,000 liters = 100 $m.^3$

3. 1 metric ton = 1,000 kg. = 2,205 lb.

4. Cubic feet per second x 5.39 x mg./liter = lb./day

5. Million gallons per day x 8.34 x mg./liter = lb./day

6. 1 acre = 4,840 $yards^2$ = 43,560 $feet^2$ = 4,047 $meters^2$ = 0.4047 hectare

7. Acre-inches x 0.226 x mg./liter = lb./acre

8. ha-cm x 0.1 x mg./liter = kg./hectare

9. English-metric conversions

   a. acre-inch x 102.8 = $meter^3$

   b. quart x 0.946 = liter

   c. English ton x 0.907 = metric ton

   d. English tons/acre x 2.242 = metric tons/hectare

   e. lb./acre x 1.121 = kg./hectare

   f. 1 $ft.^3$ = 7.48 gallons = 28.3 liters = 62.4 lb. water

   g. 1 lb. = 0.454 kg.

Appendix D

PUBLICATIONS PERTINENT TO
Application of Sewage Sludge and Wastewater to Agricultural Land

A. *Proceedings of Conferences and Symposia*

1. Recycling Treated Municipal Wastewater and Sludge Through Forest and Crop Land. Edited by W. E. Sopper and L. T. Kardos. Symposium held August 21-24, 1972. The Pennsylvania State University Press, University Park, Pa.

2. Recycling Municipal Sludges and Effluents on Land. Joint conference held July 9-13, 1973, Champaign, Ill. National Association of State Universities and Land-Grant Colleges, Washington, D.C.

3. Ultimate Disposal of Wastewaters and Their Residuals. Symposium held April 26-27, 1973, Durham, N.C. North Carolina Water Resources Research Institute, Raleigh, N.C.

4. Land for Waste Management. Conference held Oct. 1-3, 1973, in Ottawa, Ontario. The Agricultural Institute of Canada, Ottawa, Ont.

5. Land Disposal of Municipal Effluents and Sludges. Conference held March 12-13, 1973, at Rutgers Univ., New Brunswick, N.J. EPA-902/9-73-001.

6. Wastewater Use in the Production of Food and Fiber--Proceedings. Conference held March 5-7, 1974, at Oklahoma City, Okla. EPA-660/2-74-041, June 1974.

7. Municipal Sludge Management. Conference held June 11-13, 1974, in Pittsburgh, Pa. Information Transfer, Inc., Washington, D.C.

8. Municipal Sludge Management and Disposal. Conference held August 18-20, 1975, in Anaheim, Calif. Information Transfer, Inc., Rockville, Md.

9. Virus Survival in Water and Wastewater Systems. Edited by J. F. Malina, Jr. and B. P. Sagik. Symposium held in April 1974 at the University of Texas-Austin. Center for Research in Water Resources, University of Texas, Austin, Texas.

B. *EPA Reports -- Sewage Wastewaters and Sludge*

1. Survey of Facilities Using Land Application of Wastewater, by R. H. Sullivan, M. M. Cohn, S. S. Baxter. EPA-430/9-73-006, July 1973.

2. Wastewater Treatment and Reuse by Land Application - Volume I - Summary, by C. E. Pound and R. W. Crites. EPA-660/2-73-006a, August 1973.

3. Wastewater Treatment and Reuse by Land Application - Volume II, by C. E. Pound and R. W. Crites. EPA/660-2-73-006b, August 1973.

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